A Guide to Coal Mine/Greenhouse Projects

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Glossary of Frequently Used Terms

Coalbed methane: Methane that resides within coal seams.

Coal mine methane: As coal mining proceeds, methane contained in the coal and surrounding strata may be released. This methane is referred to as coal mine methane since its liberation resulted from mining activity. In some instances, methane that continues to be released from the coal bearing strata once a mine is closed and sealed may also be referred to as coal mine methane because the liberated methane is associated with a coal mine.

Degasification system: A system that extracts methane from a mine. Technically, the term degasification refers to removal of methane by ventilation and/or drainage. However, the term is most commonly used to refer to removal of methane by drainage technology. These systems include vertical pre-mine wells, gob wells and in-mine boreholes.

Ventilation system: A system that is used to control the concentration of methane within mine working areas. Ventilation systems consist of powerful fans that pump large amounts of air into mine working areas to dilute methane concentrations.

British Thermal Unit (BTU): An accepted standard for comparing the heating values of fuels. Specifically, the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Kilowatt Hours (kWh): A measurement of power over a period of one hour. A watt is defined as one joule (i.e., a unit of energy) per second.

Executive Summary

Greenhouse operators that are considering constructing a new facility should investigate the possibility of locating a greenhouse near an active underground coal mine. Although greenhouses and coal mines seemingly have nothing in common, underground coal mines may provide several resources, including coal mine methane (CMM) and coal mine water (CMW), that greenhouse operators could use as a low-cost fuel and as an irrigator, respectively. Thus, both greenhouse operators and coal mine operators could realize financial benefits from the development of coal mine/greenhouse projects. For example, greenhouse operators with a 500 billion Btu/year heating requirement could save up to $500,000 in fuel costs annually if they were able to buy CMM at a $1.00/million Btu (mmBtu) savings relative to what they would pay for natural gas.

The United States Environmental Protection Agency (U.S. EPA) prepared this report primarily for greenhouse operators who are evaluating possible sites for the construction of new, large greenhouses. Other groups, however, including coal mine operators and economic development groups in mining communities, should also find this report useful.

Coal Mine Resources and Greenhouse Project Opportunities

This report identifies three different ways in which greenhouse operations can take advantage of various underground coal mine resources in order to lower costs and increase revenues. The coal mine resources and their potential uses are:

- using coal mine methane for greenhouse heating;
- using coal mine methane to generate electricity for greenhouses; and
- using coal mine water for greenhouse irrigation and humidity.

Reduced heating costs are the main benefit of locating a greenhouse near a coal mine; CMM/greenhouse projects should be profitable based on the annual savings from reduced heating costs alone. The additional possible savings on electricity and water may make projects even more attractive.

Using Coal Mine Methane for Greenhouse Heating

Coal mine methane is natural gas released from coal seams during mining that a greenhouse operator can use to meet the heating needs of a greenhouse operation. All underground mines use ventilation systems to remove methane from mine workings to ensure that the concentration of methane remains within safe tolerances. Additionally, some particularly gassy underground coal mines employ degasification systems to remove methane from the mine. These degasification systems, which consist of either wells drilled from the surface or boreholes drilled inside the mine, recover methane in high concentrations. In many situations, energy projects can use the methane recovered from degasification systems in place of conventional natural gas.

Both greenhouse operators and coal mine operators can benefit from developing a CMM/greenhouse heating project. A greenhouse operator would negotiate with a coal mine operator to purchase CMM under terms that are more favorable to the greenhouse operator than purchasing natural gas from a local gas company. The coal mine operator would profit from selling CMM that would otherwise have been wasted.

The economics of CMM/greenhouse projects will be most favorable for very large greenhouses located in close proximity to a coal mine, but large greenhouses located several miles from the coal mine also may be able to benefit from purchasing CMM. Finally, small CMM/greenhouse projects may also be financially feasible in some circumstances.

Using Coal Mine Methane to Generate Electricity and Thermal Heat for Greenhouses

Coal mine methane can be used to generate electricity to meet the power needs of greenhouses. Previous U.S. EPA studies have shown that it would be profitable for coal mines to use CMM to generate electricity to meet on-site electricity needs. Very gassy coal mines with degasification systems should be able to generate electricity at a cost that is well below retail industrial electricity prices. Accordingly, coal mines should be able to realize significant savings by self-generating as opposed to purchasing electricity. These savings could be transferred to greenhouse operators who purchase power from the coal mine. Adding the power needs of a greenhouse to those of a coal mine would make the CMM-fueled electricity generation project even more profitable (see Case Study D).

In addition, CMM-fueled electricity generation produces thermal heat. The developer could configure the project so as to be able to pipe this waste heat to a greenhouse for heating purposes.

Using Coal Mine Water for Greenhouse Irrigation

Underground coal mines produce large volumes of water as part of mining operations. Federal regulations require that coal mines treat this water prior to disposing of it. Since greenhouses are large consumers of water, it is possible that greenhouses could use some of the CMW. The primary factor impacting the economics of using CMW in a greenhouse would be whether the water would require additional treatment prior to use in a greenhouse, and the cost apportionment agreed to by both parties. For example, it is assumed that a coal mine might incur the costs necessary to treat the CMW so that it meets governmental standards, and that a greenhouse would incur the costs of any additional treatment needed as well as any transportation costs. Provided that the costs incurred by the greenhouse are less than the costs of buying conventional water, then the use of CMW would be feasible. Other arrangements, such as the payment of transportation costs by the coal mine operator, may also be possible. The coal mine operator may agree to this latter proposal if he/she thinks that the cost of treatment and transportation is less than the cost of treatment and disposal.

Benefits of Coal Mine/Greenhouse Projects

Coal mine methane/greenhouse projects yield a wide range of benefits to many different parties. Specifically, these projects provide financial benefits to greenhouse operators, coal mine operators, and gas and power project developers. Additionally, such projects create significant economic development benefits for local mining communities. Finally, coal mine/greenhouse projects produce important environmental benefits.

- **Financial Benefits to Greenhouse Operators.** Coal mine methane/greenhouse projects could enable greenhouse operators to reduce their energy costs significantly, primarily by purchasing CMM for heating. As mentioned before, a greenhouse with a 500 billion Btu per year heating requirement could save $500,000 annually if they were able to buy CMM at a $1.00/mmBtu savings relative to what they would pay for natural gas. Additionally, purchasing electricity and/or waste heat generated by a CMM power project can also lead to significant decreases in energy expenditures. Finally, recycled CMW may provide a readily available and economical source for greenhouse irrigation.

- **Financial Benefits to Coal Mine Operators.** Coal mine operators will benefit from selling otherwise wasted resources to greenhouse operators. In particular, selling recovered CMM that would otherwise have been vented is a proven method for coal mines to generate additional income. Furthermore, supplying electricity and thermal heat to greenhouses could both generate income and enhance the cost-effectiveness of a coal mine's power generation project.

- **Economic Benefits for Localities.** A greenhouse collocated with a coal mine will produce economic development benefits for the coal mine's community, particularly with respect to job creation. A greenhouse project would also produce additional corporate and personal tax revenues for the local jurisdiction.

- **Environmental Benefits.** Using CMM for greenhouse operations, either directly or through electricity generation, will produce significant global and local environmental benefits. Because methane is a potent greenhouse gas (21 times more potent than carbon dioxide over a 100-year time period), using methane that coal mines would have otherwise vented will help reduce the potential for global warming. In addition, greenhouse use of CMM averts the need for utilities or other power suppliers to generate energy for greenhouse use. Finally, greenhouse use of recycled CMW will help to preserve the local water supply.

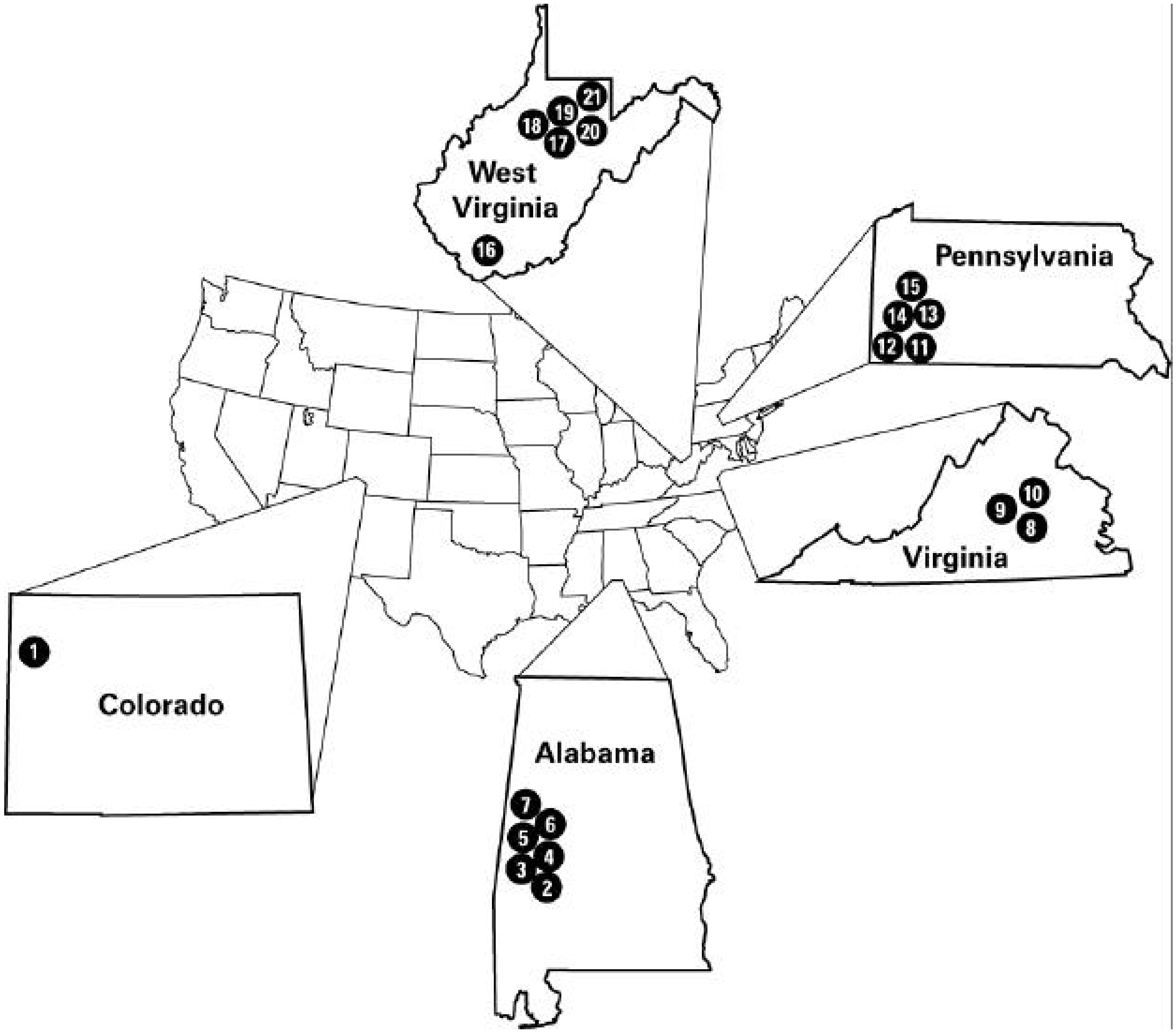
Promising Locations for Coal Mine/Greenhouse Projects

The U.S. EPA has identified 21 coal mines that may be especially promising candidates for the development of CMM/greenhouse projects. All 21 of these coal mines already have degasification systems in place. The coal mines are located in the states of Alabama, Colorado, Pennsylvania, Virginia, and West Virginia as shown in Figure 1. In addition to providing greenhouses with a low-cost source of fuel and other potentially valuable resources, many of these 21 coal mines offer other locational benefits, such as access to good transportation and to regional markets.

Next Steps: Looking Into Project Opportunities

This report provides an introduction to coal mine resources and greenhouse project opportunities. For further information, readers should contact the U.S. Environmental Protection Agency's Coalbed Methane Outreach Program (CMOP). Contact information for CMOP is provided at the end of this report.

Figure 1: Map of the United States Showing Location of Candidate Underground Mines



Legend: 1. Rio Blanco County, Colorado: Deserado Mine; 2,3,4. Tuscaloosa County, Alabama: Blue Creek Nos. 4, 5, and 7 Mines; 5,6,7. Jefferson County, Alabama: Blue Creek No. 3, Oak Grove, and Shoal Creek Mines; 8,9,10. Buchanan County, Virginia: Buchanan No. 1, VP No. 3, and VP No. 8 Mines; 11,12,13,14,15. Greene County, Pennsylvania: Enlow Fork, Emerald No. 1, Bailey, Robinson Run No. 95 and Dilworth Mines; 16. Wyoming County, West Virginia: Pinnacle No. 50 Mine; 17. Harrison County, West Virginia: Robinson Run No. 95; 18. Marion County, West Virginia: Loveridge No. 22 Mine; 19,20,21. Monongalia County, West Virginia: Blacksville No. 2, Federal No. 2, and Humphrey No. 7 Mines.

Introduction

The notion of locating a greenhouse near to an underground coal mine so as to take advantage of a coal mine's resources may seem strange. However, underground coal mines have several wasted resources that could be used as low-cost resources in a greenhouse operation, including coal mine methane (CMM) and coal mine water (CMW). Both greenhouse operators and coal mine operators can realize financial benefits from the development of coal mine/greenhouse projects.

This report is written primarily for greenhouse operators who are evaluating possible sites for the construction of new, large greenhouses. Other groups, however, including coal mine operators and economic development groups in mining communities, should also find this report useful. The report includes three main sections and three appendices:

- Section 1 describes different coal mine resources and outlines how these resources can be used in a coal mine/greenhouse project.

- Section 2 discusses the costs and benefits to greenhouse operators associated with each of the different project options discussed in Section 1. Section 2 also discusses advantages and risks to a greenhouse operator of using CMM and CMW compared with using conventional resources. Finally, Section 2 discusses benefits to other parties, such as the coal mine operator and local mining communities.

- Section 3 provides detailed information on 21 underground coal mines that may provide especially promising locations for CMM/greenhouse projects. These 21 coal mines are located in the states of Alabama, Colorado, Pennsylvania, Virginia, and West Virginia.

- Appendix A provides an analysis of the economics of CMM/greenhouse projects using several hypothetical coal mines and greenhouses. The case studies illustrate that, while the project economics are highly site specific, there are a wide range of conditions under which a CMM/greenhouse project will be profitable both to greenhouse operators and to coal mine operators.

- Appendix B provides information on Greene County, Pennsylvania, since several of the 21 candidate coal mines are located in Greene County. Appendix B provides information on the suitability of the region for a CMM/greenhouse project, including information on climate, water supply, access to transportation, taxes, and other issues.

- Appendix C lists the references used in preparing this report.

Section 1: Coal Mine Resources and Greenhouse Project Opportunities

This section provides an overview of coal mine resources and how they can be used in a greenhouse, including:

- using coal mine methane (CMM) for greenhouse heating;
- using coal mine methane to generate electricity for greenhouses; and
- using coal mine water (CMW) for greenhouse irrigation and humidity.

In addition to providing an overview of coal mine resources and project opportunities, this section discusses technical issues associated with each of the different types of projects.

Using Coal Mine Methane for Greenhouse Heating

Evaluating the potential for greenhouses to use CMM for heating is the main focus of this report. Greenhouses can use CMM in place of conventional natural gas resources as the primary heating fuel.

What Is Coal Mine Methane?

Methane is produced as a by-product of the coalification process, a process in which peat moss or other vegetation is converted into coal through geological and biological processes over time. The methane contained in coal seams and in the surrounding strata is released during mining or through natural erosion and faulting.

All underground mines use ventilation systems to ensure that methane concentrations remain within safe tolerances (methane is explosive in concentrations of 5 to 15 percent in air). Ventilation systems pump large volumes of air through the mine to dilute the in-mine methane concentrations; the ventilation systems then extract and exhaust the diluted methane to the atmosphere (methane in ventilation air is typically less than one percent).

In addition to using ventilation systems, between 20 and 25 of the gassiest U.S. coal mines employ degasification systems as a supplement to ventilation systems in order to control methane. These degasification systems, which are wells drilled from the surface or boreholes drilled inside the mine, remove methane before or after mining of the seam. Unlike ventilation systems, degasification systems recover methane in high concentrations. Degasification systems that recover methane in advance of mining recover nearly pure methane (>97% methane). These pre-mining degasification systems include vertical wells and horizontal boreholes. Degasification systems that recover methane post-mining also recover methane with a high concentration, though the methane may sometimes be mixed with mine air. In the U.S., gob wells are the primary method used to recover methane post-mining. Gas recovered from gob wells ("gob gas") may have methane concentrations ranging from 40 percent to over 90 percent, which is of sufficient quality for most greenhouse applications. Because degasification systems recover methane in high concentrations, the gas may be used as a source of energy. In fact, methane is the principal component of natural gas. Accordingly, CMM generally can be used in place of conventional natural gas.

Fourteen active U.S. coal mines that recovered methane from degasification systems in 1996 used or sold the gas for its energy value. Most of these mines sold the recovered gas to a pipeline. One coal mine used the recovered gas to generate electricity, and another one sold recovered gas to a pipeline and also used some of the gas as a fuel in their coal drying process. The use of recovered gas to heat bathhouses or other mine facilities also has been proven feasible. In the early 1990s, CMM also was used as a fuel at a glass factory in West Virginia.

Those active coal mines not using all or a portion of the methane recovered from their degasification systems simply release the methane to the atmosphere. A number of these mines are exploring possible ways of using the gas, but have not yet identified the best options. Many of the mines recover methane using gob wells. As mentioned previously, "gob gas" may contain air mixed with the methane. Since this air must be removed before the gas can be sold to a pipeline, pipeline sales may not be an economic option for some of these mines. Accordingly, these mines may be interested in other types of methane projects that can use gob gas, such as greenhouse projects. Since varying qualities of CMM can be used in greenhouses, this report focuses on the potential to use gob gas as gob gas varies in quality and is often uneconomic for other uses and thus is simply wasted.

How Can Coal Mine Methane Be Used for Greenhouse Heating?

Greenhouses typically have substantial heating needs and CMM can be used as a heating fuel instead of natural gas. A coal mine operator or gas project developer can recover methane from degasification systems and transport that gas to the greenhouse for use in a gas-fired heating system.

Depending on the fuel needs of the greenhouse, the project might require gas production from just one well or borehole, or from several wells. A wellhead compressor and gathering line would be placed at each well or borehole. For a small greenhouse project, the gas flow rate from just one gob well may be sufficient to meet all of the greenhouse's heating fuel needs. A single gob well can produce gas for a few weeks, several months, or a few years. If the greenhouse just required gas from one well, a gathering line would run from the well directly to the greenhouse. Accordingly, as an individual gob well ceases production, the wellhead compressor and gathering line equipment would need to be moved from one well to the next. For larger greenhouse projects, gas from several wells or boreholes may be required to meet the heating needs. If more than one well or borehole was required at a time, the design of the gas delivery system may involve transporting gas from several wells to a central compressor before the gas is delivered to the greenhouse.

Greenhouse gas-fired heaters or boilers would require only limited retrofitting to operate on gob gas (medium-quality CMM) rather than natural gas. Retrofitting of the equipment may be required given that the gob gas will contain some amount of air, and, thus, would have a lower heating value than does conventional natural gas. The only gas processing that would be required is de-watering of the gas.

The coal mine operator might be responsible for designing, building, and managing the gas supply system. More likely, however, the coal mine operator would contract with a gas project developer to develop and maintain the gas supply system. This gas project developer would work closely with both the coal mine operator and the greenhouse operator to ensure that the project met the needs of both parties. This report assumes that the greenhouse operator would not be responsible for developing and managing a CMM gas supply system.

Can Coal Mine Methane Meet All of the Heating Needs of a Greenhouse For Many Years?

The amount of fuel needed to heat a greenhouse depends on several factors, including the surface area of the greenhouse, the temperature, wind, sunlight and other weather conditions in the area, and the construction materials used in the greenhouse. The number of days or months during which a greenhouse requires at least some heating varies significantly from state to state (and within states). A coal mine would need to be able to supply enough gas to meet the maximum fuel needs of a greenhouse on a cold winter day, or the greenhouse would need access to back-up fuel sources. Table 1 provides sample ranges of heating needs for different sizes and types of large greenhouses.

Table 1: Typical Heating Needs of U.S. Greenhouses

Size (Million Square Feet)	Heating Demand (billion Btu per year)	
	Glass	PE (Plastic)
0.5	56-124	30-68
1.0	111-247	61-136
1.5	175-387	96-213
2.0	223-493	122-271

Each of the coal mines that currently use degasification systems, but that have not developed uses for the recovered gas, liberates more than enough methane to heat the largest U.S. greenhouses as described in Table 1. Table 2 shows the estimated annual amount of energy that could be supplied by CMM recovered from degasification systems at 18 of the top 21 candidate mines identified in this report. (Section 3 provides further detail on the complete list of candidate mines.)

Table 2: Annual Energy Available from Methane Recovered from Degasification Systems

Mine Name	Estimated Annual Energy Available from Degas Systems (billion Btu per year)
Bailey	1,205
Blacksville No. 2[1]	1,460
Blue Creek No. 3[2]	--
Blue Creek No. 4[2]	--
Blue Creek No. 5[2]	--
Blue Creek No. 7[2]	--
Cumberland	584
Deserado	110
Dilworth	621
Emerald No. 1	1,424
Enlow Fork	2,081
Federal No. 2[4]	1,898
Humphrey No. 7[1]	1,132
Loveridge No. 22[1]	1,059
Oak Grove[3]	550
Pinnacle No. 50[4]	3,398
Robinson Run No. 95	657
Shoal Creek[4]	398

[1]In 1996 a recovery system was installed at these mines. Enrichment and use of the recovered gas began in 1997. Thus, the estimates assume that no use was taking place since the estimates are based on 1996 data.

[2]These mines sell to pipeline practically all of the methane that is recovered. The operator, however, shuts-in gob wells once the quality of the gas falls below pipeline grade. A greenhouse operator may still want to approach this operator as the potential quantity of gob gas that could be produced is tremendous.

[3] This mine sells approximately 85% of the recovered methane to pipeline. The remaining gob gas is not used.

[4]This estimate accounts for gas that is sold to pipeline. The use options/amount of gas used may have expanded at this site since 1996.

Source: U.S. EPA, Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Draft Profiles of Selected Gassy Underground Mines, September 1997.

The amount of methane that a coal mine recovers from degasification systems each day (and ultimately each year) will fluctuate somewhat, depending on the number of wells in operation, coal mining rates, and other factors. However, given that the estimated average daily methane recovery from degasification systems significantly exceeds the typical energy needs of large greenhouses, some fluctuations in daily methane recovery would not impact the coal mine's overall ability to supply gas to meet heating needs, even during peak times. The overall gas quality (methane concentration and heating value) may also vary somewhat from day to day. However, a gas project developer can manage the quality of the gas flow to ensure that variations remain within the tolerances allowed in the greenhouse heating system.

A final consideration for greenhouse operators evaluating CMM project opportunities is the projected productive lifetime of the coal mine. All of the top candidate coal mines identified in this report have projected productive lifetimes of more than five years. Additionally, a majority have projected productive lifetimes of more than ten years. However, even if the coal mine were to cease operation sooner than expected, the coal mine operator or gas project developer would likely still be able to supply all or most of the greenhouse's energy requirements by recovering gas from abandoned mine workings. In fact, a CMM/greenhouse project in Illinois already uses methane from abandoned mine workings as heating fuel for several small greenhouses.

Using Coal Mine Methane to Generate Electricity and Thermal Heat for Greenhouses

How Would a Coal Mine Methane/Greenhouse Electricity Project Work?

In addition to being used directly for heating, CMM also can be used to generate electricity. Both gas turbines and internal combustion engines can operate on CMM. Similar to using CMM for heating, the only processing of the gas required before using it to generate electricity is de-watering. Coal mine methane-generated electricity can be used to meet the electricity requirements of a greenhouse. Furthermore, the thermal heat generated from the electricity generation process can be used to supply additional heat for a greenhouse.

Similar to a greenhouse heating project, a greenhouse electricity project would likely involve three parties – the greenhouse operator, the coal mine operator, and a gas project developer. Additionally, for a power generation project, a separate power project developer might also be involved. The gas project developer and/or power project developer would be responsible for supplying electricity to the greenhouse.

Can Coal Mine Methane Meet All of the Electricity Needs of a Greenhouse?

Greenhouses can have significant electricity needs stemming from lighting requirements, cooling needs, and advanced automated features. A typical greenhouse might require from 2 kWh per square foot per year to 8 kWh per square foot per year. Table 3 shows the estimated annual electricity requirements for different sizes of greenhouses.

Table 3: Typical Annual Electricity Requirements at Greenhouses of Different Sizes (MWh per year)

Greenhouse Size (million square feet)	2 kWh/square foot/year	5 kWh/square foot/year	8 kWh/square foot/year
0.5	1,000	2,500	4,000
1.0	2,000	5,000	8,000
1.5	3,000	7,500	12,000
2.0	4,000	10,000	16,000

Table 4 shows the annual electricity that could be generated from methane recovered from degasification systems for a few of the coal mines identified as the top candidate mines for greenhouse projects. Table 4 shows that the electricity requirements of typical U.S. greenhouses are considerably lower than the potential electricity that could be generated using CMM.

Coal mines are also large consumers of electricity. Accordingly, a coal mine considering supplying electricity to a greenhouse would likely develop a project that involved supplying electricity to both the mine and the greenhouse. Even though coal mines are large consumers of electricity themselves, there are a number of reasons why coal mine operators would be willing to consider selling electricity and heat generated by turbines or internal combustion engines to a greenhouse. These reasons are discussed in Section 2 of the report and in Appendix A (Case Studies).

Table 4: Estimated Potential Electricity Generation at Selected U.S. Underground Coal Mines

Mine	Potential Electricity Generated (MWh/yr)	Potential Electric Generating Capacity (MW)
Bailey	109,545	12.5
Cumberland	53,091	6.1
Deserado	10,000	1.1
Dilworth	56,454	6.4
Emerald No. 1	129,454	14.8
Enlow Fork	189,181	21.6
Federal No. 2	172,545	19.7
Humphrey No. 7[1]	102,909	11.7
Loveridge No. 22[1]	96,273	11.0
Robinson Run No. 95	59,727	6.8

[1]In 1996 a recovery system was installed at these mines. Enrichment and use of the recovered gas began in 1997. Thus, the estimates in the above table assume that no use was taking place since the estimates are based in 1996.

Note: Calculations assume a heat rate of 11,000 Btus/kWh.

Source: U.S. EPA, Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Draft Profiles of Selected Gassy Underground Mines, September 1997.

Using Coal Mine Water to Meet Greenhouse Irrigation and Humidity Needs

What is Coal Mine Water (CMW)?

Coal seams and the strata surrounding them contain water. The amount of water contained in coal seams varies significantly from one mine to the next. In order to mine the coal, coal mine operators must pump the water to the surface, where it is treated in settling ponds or through other methods. Once the water has been treated, it can be land applied or released into nearby rivers. Prior to mining, coal mine operators must file a National Pollutant Discharge Elimination

System (NPDES) permit, which describes the water treatment method and type of disposal to be used at the site. In some cases, the coal mine would be discharging water into a stream or river (i.e., open discharge), and would have to meet stringent federal and state water quality requirements.

How Would a Coal Mine/Greenhouse Water Project Work?

Depending on the quality and treatment processes required, CMW could potentially be used in a greenhouse. The CMW could be transported to a greenhouse where it would be used for irrigation or for increasing humidity levels, which is required for certain types of crops. Using CMW could potentially be more economic than purchasing water from local sources or drilling a well to supply the greenhouse. The principal concern would be the quality of the water and its suitability for different greenhouse water needs.

In cases in which the quality of the CMW is suitable for crop irrigation and/or for increasing humidity, the greenhouse owner or mine operator would need to install pipelines and pumps capable of transporting the water to the greenhouse. Both pipelines and pumps are readily available.

Can a Coal Mine Meet All of The Water Requirements of a Greenhouse?

Not surprisingly, greenhouses are great users of water. For example, a 1-acre greenhouse might require 10,000 gallons of water per day (Langhans 1990, Nelson 1993, Boodley 1996). Table 5 provides estimated water requirements for different sizes of greenhouses. Water requirements for similar sized greenhouses, however, can vary significantly, depending on crop type and other factors.

Table 5: Typical Water Requirements of U.S. Greenhouses

Greenhouse Size (million square feet)	Estimated Water Demand (gallons/day)
0.5	115,000
1.0	230,000
1.5	345,000
2.0	460,000

In comparison, underground coal mines may produce as much as one to three barrels of water (31.5 to 94.5 gallons of water) for every ton of coal mined. The candidate coal mines identified in this report produce from one million tons to over five million tons of coal every year. Accordingly, most of the coal mines would be able to meet all or a very large portion of the annual water needs of a greenhouse. Table 6 provides estimated water production rates for different sizes of coal mines.

Table 6: Typical Water Production Rates of U.S. Underground Coal Mines

Mine Production (million tons coal per year)	Estimated Water Production Rate at Coal Mines (gallons/day)
2	172,603 - 517,808
4	345,205 - 1,035,616
6	517,808 - 1,553,425
8	690,411 - 2,071,233

Section 2: Economic Evaluation of Project Opportunities

This section evaluates the economics of coal mine/greenhouse project opportunities from the perspective of a greenhouse operator. As mentioned earlier, greenhouse operators may be able to achieve significant savings on their annual energy costs and water costs. Reduced heating costs are the main benefit of locating near a coal mine; CMM/greenhouse projects can be profitable based on the annual savings from reduced heating costs alone. The additional possible savings on electricity and water may make projects even more attractive. For each project option, the section discusses project costs, project benefits, and the advantages and risks of the project. While project costs and benefits are addressed from the perspective of a greenhouse operator, the section also shows that projects would be beneficial to coal mine operators and other groups.

Economic Analysis of Using Coal Mine Methane for Heating

By locating a greenhouse near a coal mine, greenhouse operators may be able to significantly reduce their heating costs. This section examines the costs and benefits of a CMM/greenhouse heating project from the perspective of the greenhouse operator. The report assumes that the coal mine operator and/or a gas project developer would be responsible for designing, constructing, and operating a gas supply system. In other words, the greenhouse operator would purchase gas from the coal mine operator or gas project developer, but would not be responsible for the costs of building and maintaining the system.

The basic assumptions of this analysis are that:

1) Coal mine operators and/or gas project developers will only be interested in selling gas to a greenhouse if such a project will be profitable and if the economics of the project are better than the economics of the next best alternative for using or selling the gas (normally, selling the gas directly to a natural gas pipeline); and

2) Greenhouse operators will only be interested in purchasing gas from coal mines if they can purchase the gas at a price that is lower than typical commercial or industrial end-user gas prices, thus achieving significant annual savings on their heating costs.

As described in this section, for many coal mines, the cost of supplying CMM to a greenhouse will be significantly lower than the typical commercial or industrial end-user gas prices. Accordingly, the coal mine and/or gas project developer may be able to negotiate a price with the greenhouse operator that leads to financial benefits for both parties.

Project Costs

The major capital costs associated with supplying gas to a greenhouse are costs for compressors and pipelines to move the CMM to the greenhouse. Additional costs include safety and monitoring equipment, and a dehydrator to remove water from the CMM. The major operating costs for the project would be those associated with moving gathering lines, and operating and maintaining the gas gathering system. This report assumes that the coal mine operator and/or a gas project developer would be responsible for designing, constructing, and operating a gas supply system. The greenhouse operator would purchase CMM from the coal mine operator or gas project developer, but would not be responsible for the costs of building and maintaining the system. This report further assumes that the greenhouse operator would only be responsible for the cost of modifying a gas-fired heater or boiler so that the equipment would operate on CMM. The greenhouse operator would need to modify the equipment if the Btu value of the CMM were lower than that of conventional natural gas. The average cost for retrofitting gas-fired heating equipment would be only about $500 as minimal retrofits would be required (Frece 1997).

Because this report assumes that the greenhouse operator will not be responsible for the costs of constructing and maintaining a gas supply system, this section does not present detailed information on capital and operating costs for different pieces of gas gathering equipment. (Appendix A provides further information for readers interested in learning more about the subject.) Instead, the discussion on project costs presented here focuses on the overall cost per unit of energy supplied ($/million Btus (mmBtu)) and on the conditions under which CMM/greenhouse projects will likely be feasible. Detailed information supporting the conclusions described here is shown in Appendix A, where several case studies examine the economics of CMM/greenhouse projects.

The $/mmBtu cost of supplying CMM to a greenhouse (and, ultimately, the price at which CMM could be sold to a greenhouse) will vary depending on conditions at the coal mine and the characteristics of the planned greenhouse. The specific conditions and characteristics impacting CMM supply costs are discussed in further detail below. The overall cost of supplying coal mine gas can range from as low as $0.50/mmBtu to well over $6/mmBtu, but generally is in the range of $2/mmBtu. In addition to covering capital and operating costs for the project, however, the coal mine operator or gas project developer also will want to make a profit from the project and attain a certain desired rate of return. Accordingly, the coal mine operator or gas project developer will need to set a gas sales price that is higher than the CMM supply cost. At most of the candidate mines identified in this report, the cost of supplying CMM to a greenhouse would probably be well below typical end-user prices for natural gas since the greenhouse would be located near the coal mine (see Appendix A for further information on gas supply costs). When the CMM supply costs are significantly lower than typical end-user prices for natural gas there is a potential for both coal mine operators and greenhouse operators to benefit.

The overall $/mmBtu cost of supplying gas to a greenhouse will vary significantly depending on site-specific conditions at the coal mine and on characteristics of the planned greenhouse. Following is a summary of the major factors impacting gas supply costs.

- In general, the cost of supplying gas (CMM or conventional natural gas) to a large greenhouse (with high energy needs) is significantly lower than the cost of supplying gas to a smaller greenhouse (with low energy needs). The cost of supplying gas to a larger greenhouse is lower because there are significant fixed costs involved in establishing and maintaining a gas supply system and these costs must be paid regardless of whether the greenhouse is large or small. As shown in the case studies, the cost of supplying gas to a very large greenhouse may be lower than $1.00/mmBtu at some mine sites under certain conditions. While large CMM/greenhouse projects will likely have the lowest supply costs, small CMM/greenhouse projects can still be feasible. For example, some coal mines have found it economic to collect and use the methane emitted from a single gob well for hot water heating at the mine bathhouse. Likewise, a small CMM/greenhouse project might have gas supply costs similar to that of a small hot-water heating project.

- The distance between the coal mine and the greenhouse is a major factor determining the overall $/mmBtu cost of supplying gas to a greenhouse. Small CMM/greenhouse projects would have to be located near (or on the premises of) the coal mine in order to be economic. Larger CMM/greenhouse projects could be located several miles away. In fact, as shown in Appendix A, CMM supply costs could potentially still be below $2.00/mmBtu for very large greenhouses located nearly ten miles from the coal mine.

- Greenhouses typically may only have a large demand for natural gas during the winter months when they require gas for heating. A gas supply system would likely be designed to handle gas flow rates compatible with peak needs during winter months. Accordingly, during the summer months, the gas supply system may not be used at all, or may only carry a limited amount of gas compared to the capacity of the system. The fact that greenhouses would have a seasonal demand for gas tends to increase the $/mmBtu cost of supplying gas (compared to selling gas to a pipeline on a year-round basis). However, as shown in Appendix A, CMM/greenhouse projects still may be economic even though gas purchases would likely vary significantly on a seasonal basis.

- Coal mines that have degasification systems in place are the best candidates for supplying CMM to greenhouses. Because these coal mines already recover methane, the cost of drilling a well or borehole would not be an incremental cost associated with a CMM/greenhouse project. Section 3 of this report identifies 21 gassy underground coal mines that already employ degasification systems.

- Other site-specific conditions at a coal mine also will impact the cost of supplying gas. For example, an especially gassy coal mine may be able to meet the energy needs of a greenhouse by recovering methane from just one gob well. A less gassy mine, however, might need to use three gob wells to meet the same energy needs. The cost for the coal mine that is able to supply gas from just one well would likely be lower, since the project would require fewer wellhead compressors and less total footage of gathering lines. Further, a site that has a flat topography also will be advantageous since the cost of laying gathering lines will be less.

While the overall cost of supplying gas to a greenhouse will vary based on the factors described above, there are a wide range of conditions under which a CMM/greenhouse project will be profitable to greenhouse operators, coal mine operators, and gas project developers. Appendix A provides specific examples of different situations in which CMM/greenhouse projects would be profitable ventures for all parties involved. Appendix A also provides further detail on the assumptions used in the analysis.

Project Benefits

As described above, coal mine operators may be able to supply CMM to greenhouses at prices that are below typical end-user natural gas rates, which translates into energy cost savings for greenhouse operators. Because the cost of supplying gas to a greenhouse would vary significantly for different mines, the gas purchase price would need to be determined on a site-specific basis, through negotiations between the greenhouse operator and the coal mine operator or gas project developer. Potential savings could range from as low as $0.10/mmBtu to over $1.00/mmBtu.

Given that heating costs account for a large portion of greenhouse annual operating costs, significant reductions in these costs would mean greatly increased profits for a CMM/greenhouse project. Table 7 shows estimated potential annual savings to greenhouse operators for different sizes of greenhouses with different annual energy needs.

Table 7: Potential Annual Savings to Greenhouse Operators

$/mmBtu Savings	Greenhouse Energy Needs (billion Btu/yr)			
	30	**200**	**350**	**500**
$0.25	$7,500	$50,000	$87,500	$125,000
$0.50	$15,000	$100,000	$175,000	$250,000
$0.75	$22,500	$150,000	$262,500	$375,000
$1.00	$30,000	$200,000	$350,000	$500,000

Table 8 shows the estimated net present value of these savings for a project lasting ten years. For greenhouses with energy needs in the range of 30 billion Btus per year, the estimated annual savings would likely exceed several thousand dollars per year. The net present value of these savings for a ten-year project could range from $46,000 to over $180,000. For the largest greenhouses, which have energy needs in the range of 500 billion Btus per year, annual savings would likely exceed several hundred thousand dollars per year. The net present value of these annual savings during a ten-year project could exceed $3 million.

Table 8: Net Present Value of Annual Savings to Greenhouse Operators in Million $

$/mmBtu Savings	Greenhouse Energy Needs (billion Btu/yr)			
	30	**200**	**350**	**500**
$0.25	$0.046	$0.307	$0.538	$0.768
$0.50	$0.092	$0.614	$1.075	$1.536
$0.75	$ 0.138	$0.922	$1.613	$2.304
$1.00	$0.184	$1.229	$2.151	$3.072
The net present value was calculated assuming a ten year project lifetime and a nominal discount rate of approximately ten percent.				

Project Advantages and Risks

The primary reason that greenhouse operators should consider using CMM for heating is that the coal mine operator (or a gas project developer) may be able to offer a gas purchase arrangement with terms that are more favorable than purchasing gas from a local gas company. The economic benefits would likely be large enough to warrant constructing a new greenhouse in close proximity to a coal mine.

A possible disadvantage of using CMM as opposed to purchasing natural gas from a gas company is the additional time and effort required to work with a coal mine operator or gas project developer on developing specific terms of the gas purchase agreement. Additionally, purchasing gas from a coal mine would expose the greenhouse operator to some possible project risks, though many of these risks can be minimized by ensuring that the greenhouse would have access to an alternate source of fuel. For example, the greenhouse might need to be able to purchase backup gas from the local gas company if problems arose.

Possible specific project risks include:

- *Technology Risks*. Technology risks for a CMM/greenhouse project would likely be minimal. The technologies for recovering methane using degasification systems, for de-watering the gas, and for transporting the methane are proven and have been in use for many years at coal mine operations and conventional natural gas operations. Additionally, retrofitting of standard gas-fired heating equipment to operate on lower heating value gas is a proven technology. For example, many industrial and commercial operations (including greenhouses) currently purchase landfill gas for heating (landfill gas has a heating value in the range of 450 to 550 Btu per cubic foot). While the technologies for recovering, transporting, and using CMM in a gas-fired heating system are proven, there still may be occasions when the gas project developer needs to shut down the system for unexpected repairs or for routine maintenance. In order to minimize the risk of system shut-downs, the greenhouse operator would also need to have a connection to a local gas company pipeline in order to purchase back-up fuel or arrange another alternate source of fuel.

- *Risks Associated With the Mining Operation.* Gas flow rates are linked to coal production rates. Accordingly, if the mine reduces coal production, or idles or closes the mine earlier than planned, gas flow rates would be affected. Some of the risk related to the mining operation may be mitigated for three reasons. First, since CMM production at many of the 21 candidate mines exceeds the maximum amount of gas production needed at a greenhouse on a daily basis, variations in gas flow rates at the mine will likely not impact the gas supply for the greenhouse. Second, even if the mine completely ceases operations, it would still be possible to supply gas from abandoned mine workings. Third, the risks related to mining operations could also be mitigated by ensuring that the greenhouse is still able to purchase back-up fuel from the local gas company or from an alternative supplier.

- *Risks Related to Gas Project Developer.* An additional risk is related to entering into a gas purchase agreement with a gas project developer. While there is little risk associated with purchasing gas from a local gas utility, there may be some limited additional risk related to the underlying financial solvency of the gas project developer's company.

Evaluating a Coal Mine Methane/Greenhouse Project Opportunity

(The Coal Mine Operator or Gas Project Developer's Perspective)

The project developer (coal mine operator or third party) will evaluate the benefits of selling CMM to a greenhouse against other possible uses for the CMM, such as selling the CMM directly to a natural gas pipeline (an established practice at several U.S. coal mines) or using the CMM for power generation. In certain circumstances the project developer may find it advantageous to sell CMM to greenhouses for several reasons. First, methane recovered from degasification systems may be mixed with ventilation air from the mine. If the coal mine were to try to sell this gas directly to a natural gas pipeline, the air would need to be stripped from the gas, which can be costly, and is unnecessary when selling methane directly to a greenhouse. Many gassy mines do, however, sell their recovered, high-quality methane to pipelines. This gas is recovered from vertical wells and in-mine boreholes, and to a lesser extent from new gob wells. For many mines with older gob wells the recovered CMM is contaminated with air making it unsuitable for pipeline injection. Thus, the gas is often vented. Greenhouses could use this gob gas directly as fuel for a boiler or heater. Second, a developer may be interested in selling gas to a greenhouse operator since the developer could sell the gas at a price that is higher than the typical wellhead gas price (though still lower than the typical end-user gas price). Given that wellhead gas prices are in the $2/mmBtu range in many coal mining areas while the typical end-user gas prices are in the $4/mmBtu range in most areas, there is a significant margin between the price that the coal mine could receive for selling gas to a greenhouse versus the price a greenhouse would typically have to pay for conventional natural gas.

From the developer's perspective, however, there may be a few disadvantages to selling gas to a greenhouse rather than directly to a gas pipeline. First, a greenhouse may not be able to purchase all of the gas that is recovered from the coal mine. When selling gas to a pipeline company, the developer is usually able to sell all of the gas that is recovered from the mine. Since methane recovery projects involve high fixed costs, developers must sell large volumes of gas in order for the recovery and use project to be profitable. Examples of fixed costs for the project include the capital cost of purchasing compressors and gathering lines. Additionally, developers would incur significant annual operating and administrative costs regardless of the amount of gas sales. Second, another potential disadvantage of selling gas to a greenhouse is that most coal mines are located within close proximity to existing natural gas lines. Many coal mines even have gas lines crossing their mine property. Thus, the length of lines needed to transport the CMM to the gas pipelines may be minimal.

While there are some disadvantages to coal mine/greenhouse projects compared with pipeline projects, greenhouse projects typically have the potential to be more profitable than other projects. This is because the developer and greenhouse operator can negotiate a price that is beneficial to both parties, especially if there is a wide margin between the cost of supplying gas and the typical end-user gas prices. Accordingly, coal mine operators and greenhouse operators may be able to negotiate a price that leads to large financial benefits for both parties.

Overall, using CMM for heating is likely to be profitable for greenhouse operators. The potential to achieve significant savings on heating costs should significantly outweigh the limited additional project risks. Furthermore, in addition to realizing significant energy savings, a greenhouse operator may also be able to reduce other costs by constructing a greenhouse near a coal mine. Finally, another benefit of using CMM for greenhouse heating is that such a project reduces methane emissions to the atmosphere, thereby achieving global environmental benefits.

Economic Assessment of Using Coal Mine Methane for Greenhouse Electricity Needs

In addition to using CMM directly for heating, it may be used to generate electricity to meet the power needs of a greenhouse. This report assumes that there are two situations under which a CMM/greenhouse electricity project would be feasible:

- A greenhouse electricity project would likely be feasible at coal mines that already are generating electricity to meet all or a portion of their own on-site electricity needs, or are considering such a project. Currently, there are two power generation projects using CMM at U.S. coal mine sites; or

- A greenhouse electricity project might also be feasible if a coal mine and greenhouse had already developed a greenhouse heating project. Most gassy underground coal mines recover enough methane to be able to sustain a greenhouse heating project and a greenhouse electricity project, as well as an electricity project that supplies the baseload electricity needs of the mine.

This report assumes that a CMM/greenhouse electricity project by itself would likely not be feasible. Greenhouse electricity needs alone are not high enough to warrant the development costs inherent in installing an electricity project. In conjunction with an existing coal mine power generation project or a greenhouse heating project, however, a greenhouse electricity project may be economic. The potential for the greenhouse to use waste heat created by the electricity generation process may make the project even more economic.

Appendix A provides a specific example of how the economics of a CMM/greenhouse power generation project might work. The results of the analysis show that even though coal mines have their own large on-site electricity needs, coal operators should still be interested in and could profit from selling electricity to greenhouses. In particular, CMM/greenhouse electricity generation projects will be most economic at large greenhouses with high baseload electricity needs.

Project Costs

This analysis assumes that a greenhouse owner will incur no additional capital or operational costs from buying its electricity from a coal mine generation facility. The power generation facility would be operated by the coal mine or another management entity, such as an independent power project developer. Therefore, the greenhouse operator would be negotiating with a power project developer for the purchase of CMM-derived electricity.

Previous U.S. EPA studies have shown that the cost of generating electricity using CMM is likely to be significantly below industrial retail electricity rates (for example, U.S. EPA 1993). These previous reports, which focused on the potential for coal mines to generate electricity to meet their own on-site needs, indicated that coal mines could profit substantially by developing these projects. Installing capacity to meet the baseload capacity needs of the mine would yield the highest returns for the coal mine. Installing capacity to meet baseload needs is especially profitable because the full capacity of the generator could be used at all times. Installing capacity to supply electricity beyond baseload needs might also be economic. At times when the mine is not in full operation, however, coal mines would need to sell electricity generated in excess of on-site needs to a local utility or another electricity purchaser. In some cases, the buyback rates offered by local electric utilities might not be high enough to warrant the installation of additional capacity. Accordingly, selling electricity to a nearby facility, such as a greenhouse, would be more economic because the coal mine could sell electricity at a price higher than the utility buy-back price (though still lower than typical retail industrial prices).

Electricity Generation from Coalbed Methane in Australia

The Appin and Tower Coal Mines, New South Wales (Australia) use CMM to generate electricity. Between the two mines, 94 generator sets, each having a 1 MW capacity, are used to produce electricity. The electricity produced is used on-site and sold to a local utility. The project uses recovered methane as the main fuel and ventilation air released from the Appin coal mine as combustion air for the engines. In addition to being an economic success story, the project also has accounted for important global environmental benefits by reducing greenhouse gas (methane) emissions.

In cases in which the coal mine already uses methane to meet its own on-site electricity needs, the power project developer would need to determine whether the electricity needs of the greenhouse could be serviced by using the existing capacity of the on-site generator, or whether additional capacity is required. If a coal mine power generation project relied on several individual generating units, adding additional capacity would likely not be a problem. For example, the Appin and Tower coal mine power project in Australia relies on several 1 MW internal combustion engines for power generation. For projects not using this modular approach, however, adding additional capacity might not be feasible. Depending on whether the coal mine uses an internal combustion engine or gas turbine, the cost of adding additional capacity is likely to be in the range of $800 per kW.

Project Benefits

An electricity generator at a coal mine may be able to supply electricity to a greenhouse at a price that is lower than typical industrial or commercial retail electricity prices. By purchasing electricity at rates lower than typical industrial or commercial retail electricity prices, the greenhouse operator will realize substantial savings on their electricity costs. The greenhouse operator and the manager of the power project would need to decide upon a rate that would lead to financial benefits for both parties. The $/kWh savings would likely vary from project to project, depending on a number of factors relating to generating costs of the project and electricity prices in the region. Table 9 presents potential annual savings to the greenhouse operator based on different greenhouse sizes and different possible $/kWh savings. The financial benefits shown in Table 9 only reflect savings based on reduced electricity costs. The potential to use waste heat from the power generation project for greenhouse heating is not factored into the calculation of the benefits.

Table 9: Potential Annual Savings to Greenhouse Operators

$/kWh Savings	Greenhouse Electricity Needs (million kWh/yr)			
	30	**200**	**350**	**500**
$0.0025	$75,000	$500,000	$875,000	$1,250,000
$0.0050	$150,000	$1,000,000	$1,750,000	$2,500,000
$0.010	$300,000	$2,000,000	$3,500,000	$5,000,000
$0.015	$450,000	$3,000,000	$5,250,000	$7,500,000

Depending on several factors, CMM/greenhouse electricity projects should be profitable for all parties involved. These factors include the total electric generating capacity of the mine, the electricity demand pattern of the greenhouse (daily and seasonal), the electricity demand pattern of the mine, the price the coal mine pays for electricity, the price the greenhouse would pay for electricity, and the price the local utility charges for electricity. Appendix A provides a specific example of conditions under which a CMM/greenhouse project would be profitable for both the greenhouse operator and the coal mine operator.

Project Advantages and Risks

The primary reason that greenhouse operators should consider purchasing CMM-derived electricity is that a project developer may be able to offer an electricity purchase arrangement with terms that are more favorable than purchasing electricity from a local electric utility.

Currently, the major drawback of such a potential project is the limited commercial experience in the U.S.--only two CMM power generation projects are underway. However, CMM-derived power has been demonstrated elsewhere, including in Australia, Germany, the United Kingdom, Poland and China, and is under serious investigation at several mines in the U.S. Further, in some cases the greenhouse operator can be the driver of the implementation of a CMM-fueled power project. If a greenhouse operator were interested in locating near a coal mine in order to purchase gas and electricity from the mine, a coal mine operator might be encouraged to investigate the possibility of developing a power project.

Project risks are similar to the risks for greenhouse heating projects. Specifically, these risks include:

- *Technology Risks.* Several projects are underway in the U.S. and other countries that use CMM to generate electricity. These projects rely on internal combustion engines to generate electricity. Using medium-Btu gas in internal combustion engines (and also in turbines) is a proven technology. While the technology underlying the project is proven, a power generation project will face the same technology risks as a CMM/greenhouse heating project in terms of the risks associated with equipment down-times for gas gathering, gas collection, and gas dehydration equipment. Additionally, there is also the risk of unplanned down-times for the power generation equipment. A greenhouse operator can mitigate these project risks by having access to back-up power from the local electric utility in the event of an emergency. Sometimes, however, electric utilities may charge higher than normal industrial or commercial rates for purchasing back-up power.

- *Coal Mine Operator and Gas and/or Power Project Developer Risks*. These risks are similar to the risks associated with CMM/greenhouse heating projects.

In summary, the risks of a CMM power generation project are similar to those for a CMM/greenhouse heating project. Most of the risks may be mitigated by ensuring that greenhouses have access to back-up power. Overall, purchasing CMM-derived electricity will likely be very economic for a large greenhouse facility.

Economic Assessment of Using Coal Mine Water for Greenhouse Irrigation Needs

This section presents a qualitative discussion of the economic costs and benefits of a CMW/greenhouse project. This project option is not quantitatively discussed due to the site variations related to water quality, water quantity, water discharge permit conditions, local water prices, and potential for drilling a well. The discussion of a CMW/greenhouse project presented below assumes that the greenhouse owner or operator would consider using CMW only if the water discharged from the coal mine were suitable for greenhouse use without significant additional treatment. There may be instances in which CMW would need to undergo significant further treatment to meet the water quality demands of the greenhouse, but the decision as to whether to further treat the CMW would ultimately depend on the cost of the additional treatment relative to the cost of local water. Note that other agreements between the coal mine operator and the greenhouse operator can be reached, and that this report only discusses one such agreement.

Project Costs

This analysis assumes that coal mine operators would not charge a greenhouse operator to use CMW as the coal mine operator will ultimately save on disposal and transportation costs. A greenhouse operator would pay for the costs of transporting the CMW to the greenhouse and for any additional treatment and costs above the standard treatment costs that a coal mine would incur. Accordingly, a CMW/greenhouse project would involve two major project costs.

- *Water Treatment.* The quality of CMW available from site to site may vary significantly. In some cases, CMW would require additional treatment before it could be used in a greenhouse. The cost of treating CMW may range from $0.01/barrel for settling ponds to $3.00/barrel for more advanced processes such as reverse osmosis (Lee-Ryan et al. 1991). This report assumes that if significant additional water treatment were required (i.e. treatment beyond what is normally required by law), such a project might not be economic for a greenhouse operator. Depending on the treatment required, the cost of either purchasing water from local sources or of drilling a well to supply water may be less than treating mine water.

- *Water Transport.* Greenhouse operators would be responsible for the infrastructure needed to carry water to the greenhouse. The capital cost of this infrastructure is highly site specific, depending on the volume of water needed, the distance between the coal mine and greenhouse, and the topography at the site.

  - *Distance.* More piping is needed as the distance between a CMW treatment site and a greenhouse increases. Additionally, the distance between the coal mine and the greenhouse will determine the number and size of pumps required to transport the water from the coal mine to the greenhouse.

  - *Topography.* Costs associated with carrying water from the coal mine treatment site to the greenhouse will depend in part on the topography of the site. For example, fitting pipes and installing pumps to push water up hill or to avoid obstacles (e.g., roads or streams) will increase the capital costs of the water supply system.

Project Benefits

A greenhouse operator may be able to save money by using CMW, rather than purchasing water from local sources or drilling a well to supply water. Municipal water prices vary significantly depending on the state, county, and the volume of water that a facility requires. Depending on the quantity of water consumed, water prices could vary from $0.30 to $2.75 per thousand gallons of water, based on reported costs for major coal producing counties in Alabama, Illinois, Pennsylvania, West Virginia, and Virginia. Municipalities also typically charge a fee for a commercial facility to connect to a water line. This one-time connection cost is extremely variable (e.g., $45 to $475). In areas where municipal water prices are low, greenhouses may choose to purchase water from the local government instead of paying to install a CMW supply system.

Advantages and Risks

Greenhouse operators may find that using CMW for their irrigation or other water needs is economic if all of the following statements are found to be true:

- The composition of the CMW is suitable for the greenhouse's water needs without requiring significant additional treatment;
- The coal mine supplies enough water to meet all of the greenhouse irrigation demands; and
- The cost of a CMW treatment and supply system is less than the cost of other local water sources.

Due to significant fixed costs associated with a CMW/greenhouse project, the potential cost savings achievable through the use of CMW will be highest for greenhouse operations requiring large volumes of water.

An additional consideration regarding the use of CMW is that municipalities in some rural areas may have limited conventional water capacity flowing into the area and much of the available capacity may be dedicated to the existing coal mining operations. Therefore, if a greenhouse were to locate near a coal mine in order to take advantage of CMM for heating, water supply possibly might become a limiting factor unless the greenhouse were able to use CMW.

Perhaps the most significant risk associated with supplying CMW to a greenhouse is that such a project has not yet been demonstrated on a commercial basis. A greenhouse operator would likely need to invest significant resources to determine whether a CMW supply project would be feasible at a specific mine site. In particular, the greenhouse operator would need to evaluate the quality of the CMW to determine whether the water was suitable for irrigation or other greenhouse water needs and evaluate the best technical option for transporting the water. Finally, while there are a number of proven technologies available for treating CMW so that the water can be land applied or injected into streams, the costs of using these technologies might be prohibitive.

Section 3: Information on Candidate Coal Mines

The U.S. EPA has identified a minimum of 21 gassy underground coal mines that may be suitable for the development of a CMM/greenhouse project. All 21 coal mines already use degasification systems to recover methane from mine workings, thus the cost of installing a recovery system would not be part of the project costs. Some of the coal mines are venting all of the recovered methane to the atmosphere because they have not yet identified economic uses for the gas. The candidate coal mines are located in five different states – Alabama, Colorado, Pennsylvania, Virginia, and West Virginia. Tables 10 and 11 provide further summary statistics about each of the 21 mines, including volume of recovered methane, location, and contact information.

Table 10: U.S. Underground Mines with Degasification Systems

Mine	Company	Location (County, State)	1996 Estimated Emissions from Degasification System (mmcf/day)	1996 Estimated Methane Used (mmcf/day)
Enlow Fork	CONSOL	Greene County, Pennsylvania	5.7	0
Emerald No. 1	Cyprus Amax	Greene County, Pennsylvania	3.9	0
Bailey	CONSOL	Greene County, Pennsylvania	3.3	0
Robinson Run No. 95	CONSOL	Harrison County, West Virginia	1.8	0
Dilworth	CONSOL	Greene County, Pennsylvania	1.7	0
Oak Grove	U.S. Steel	Jefferson County, Alabama	9.3	7.3
Deserado	Western Fuels	Rio Blanco County, Colorado	0.3	0
Shoal Creek	Drummond Coal	Jefferson County, Alabama	3.3	9.7
Pinnacle No. 50	U.S. Steel	Wyoming County, West Virginia	10.7	1.39
Blacksville No. 2	CONSOL	Monongalia County, West Virginia	4.0	NA
Cumberland	Cyprus Amax	Greene County, Pennsylvania	1.6	0
Federal No. 2	Eastern Assoc.	Monongalia County, West Virginia	5.7	0.5
Humphrey No. 7	CONSOL	Monongalia County, West Virginia	3.1	NA
Loveridge No. 22	CONSOL	Marion County, West Virginia	2.9	NA
Blue Creek No. 3	JWR	Jefferson County, Alabama	11.0	40 mmcf/day total for all 4 mines.
Blue Creek No. 4	JWR	Tuscaloosa County, Alabama	9.8	
Blue Creek No. 5	JWR	Tuscaloosa County, Alabama	4.6	
Blue Creek No. 7	JWR	Tuscaloosa County, Alabama	14.1	
Buchanan No. 1[1]	CONSOL	Buchanan County, Virginia	NA	73 mmcf/day total for all 3 mines.
VP No. 3[1]	CONSOL	Buchanan County, Virginia	NA	
VP No. 8*[1]	CONSOL	Buchanan County, Virginia	NA	

Source: U.S. EPA, Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Draft Profiles of Selected Gassy Underground Mines, September 1997.
NA means not available.
[1] Although estimated emissions from degasification systems in 1996 are not available, estimates are that these 3 mines used approximately 73 mmcf/day of recovered methane in 1996.
* This mine is currently closed.

Table 11: U.S. Underground Mines with Degasification Systems Contact List

Mine	Contact Name/ Title	Mailing Address	Phone/ Fax Numbers
Enlow Fork	Paul Kvederis, Manager, Public Relations	322 Enon Church Road, West Finley, PA 15377	412-663-7501/ 412-663-7502
Emerald No. 1	D.P. Brown Vice President	P.O. Box 371, Waynesburg, PA 15370	412-627-7500
Bailey	D.M. Yoders, Superintendent	P.O. Box 138, Greysville, PA 15337	412-428-1100
Robinson Run No. 95	Thomas Simpson General Superintendent	P.O. Box 326, Shinnston, WV 26582	304-795-4421
Dilworth	L. Barietta General Superintendent	450 Racetrack Road, Washington, PA 15301	412-966-5065
Oak Grove	Paul Hafera General Superintendent	8800 Oak Grove Mine Road, Adger, AL 35006	205-497-0180
Deserado	Mike Weingand Mine Manager	P.O. Box 1067, Rangely, CO 81645	970-675-8431/ 970-675-5229
Shoal Creek	Don Hendrickson, Longwall Superintendent	8488 Nancy Ann Bend Road, Adger, AL 35006	205-491-6200
Pinnacle No. 50	J.R. Vilseck, Jr. Division Manager	P.O. Box 338, Pineville, WV 24874	304-732-5200
Blacksville No. 2	W.G. Devine Mine Superintendent	P.O. Box 24, Wana, WV 26590	304-662-6121
Cumberland	C.E. Zabrosky Mine Superintendent	P.O. Box 711, Waynesburg, PA 15370	412-223-5400
Federal No. 2	N.D. Gallagher Mine Manager	Route 1, Box 144, Fairview, WV 26570	304-449-1911
Humphrey No. 7	John Higgins General Superintendent	P.O. Box 100 Osage, WV 26543	304-879-5912
Loveridge No. 22	John Straface Mine Superintendent	P.O. Box 40 Fairview, WV 26570	304-662-6107
Blue Creek No. 3	G. Richmond Mine Manager	5290 Mud Creek Road, Adger, AL 35006	205-554-6350
Blue Creek No. 4	J. E. Cooley Mine Manager	14730 Lock 17 Road, Brookwood, AL 35444	205-554-6450
Blue Creek No. 5	J. Beasley Mine Manager	12792 Lock 17 Road, Brookwood, AL 35444	205-554-6550
Blue Creek No. 7	Rich Donnelly Mine Manager	18069 Hannah Creek Road, Brookwood, AL 35444	205-481-6706
Buchanan No. 1	Douglas LaForce Mine Foreman	P.O. Box 230, Route 632, Mavisdale, VA 24627	703-498-4564
VP No. 3	Paul Kvederis Manager Public Relations	322 Enon Church Road, West Finley, PA 15377	412-663-7501/ 412-663-7502
VP No. 8*	Paul Kvederis Manager Public Relations	322 Enon Church Road, West Finley, PA 15377	412-663-7501/ 412-663-7502

Source: U.S. EPA, Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Draft Profiles of Selected Gassy Underground Mines, September 1997.
* This mine is currently closed.

Conclusions

This report has shown that a greenhouse company could realize substantial financial benefits by locating a new greenhouse facility near a coal mine. Specifically, several coal mining by-products that would otherwise not be used, including coal mine methane (CMM) and coal mine water (CMW), could be used as low-cost resources in a greenhouse operation. Both greenhouse operators and coal mine operators could realize financial benefits from the development of coal mine/greenhouse projects.

This report identified several different possible coal mine/greenhouse project opportunities, including:

- using coal mine methane for greenhouse heating;
- using coal mine methane to meet greenhouse electricity needs; and
- using coal mine water to meet greenhouse water needs.

Using CMM for greenhouse heating can yield substantial savings for greenhouse operators. Additionally, the potential to reduce energy and water costs and to increase crop yields by using CMM-derived electricity and/or CMW may make coal mine/greenhouse projects even more economic for greenhouse operators.

While coal mine/greenhouse projects should lead to large financial benefits for greenhouse operators and coal mine operators, these projects also lead to economic benefits for local communities in mining regions. The addition of a new commercial facility in the area creates more jobs and increases tax revenues. Coal mine/greenhouse projects also achieve global and local environmental benefits. The use of methane for heating or for electricity generation reduces methane emissions to the atmosphere. Since methane is a potent greenhouse gas (21 times more potent than carbon dioxide over a 100-year time period), even small reductions in methane emissions lead to very large global environmental benefits.

Next Steps: Looking into Project Opportunities

Greenhouse operators interested in particular coal mines may either contact the mine operator directly or the U.S. EPA's Coalbed Methane Outreach Program (CMOP) for assistance. CMOP supports efforts around the globe to recover and use CMM. In addition to supporting technical assessments, CMOP disseminates information and provides advisory services. For example, CMOP maintains an extensive database of contacts at major coal mines in the United States and can broker local community and industry assistance as requested. To find out more about CMOP and the opportunity to use coal mine resources, please contact:

Coalbed Methane Program Manager
U.S. Environmental Protection Agency
Atmospheric Pollution Prevention Division
401 M Street, SW (6202-J)
Washington, DC 20460

Document Orders:	1-888-STAR-YES
Facsimile:	202-565-2077
Internet:	fernandez.roger@epa.gov schultz.karl@epa.gov
Homepage:	http://www.epa.gov/coalbed

Greenhouse operators seeking additional background information on the candidate coal mines can refer to "Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Draft Profiles of Selected Gassy Underground Coal Mines," September 1997, EPA 430-R-97-020. (This publication can be ordered by calling the document orders hotline at 1-888-STAR-YES.) For the most recent listing of mines with degasification systems, please contact the relevant district Mine Safety and Health Administration (MSHA) office in the area where the greenhouse will be located. A listing of district MSHA offices can be found at http://www.msha.gov.

Appendix A: Case Studies

This appendix provides further information on the financial analysis referred to in Section 2 of the report. Specifically, this appendix uses several case studies to illustrate the conditions under which coal mine methane (CMM)/greenhouse projects will be economically viable. These case studies are based on hypothetical coal mines and greenhouses. The potential energy production and project costs assumed for the hypothetical coal mines described in the case studies, however, are based on real energy data and costs at the candidate coal mines identified in this report. Furthermore, the information presented on energy needs for the hypothetical greenhouses are typical of large greenhouses in the U.S. The case studies in this appendix demonstrate that the economics of a CMM/greenhouse project are highly dependent upon site-specific conditions at the coal mine and on the energy needs, location and other aspects of the greenhouse. While the project economics are highly site-specific, this appendix shows that there are a range of conditions under which a CMM/greenhouse project will be profitable both to greenhouse operators and to coal mine operators.

This appendix presents information on the cost to coal mine operators of supplying gas and/or electricity to greenhouses. The coal mine operator/gas developer project cost information presented in this appendix is useful for greenhouse operators because it will help them understand the circumstances under which these projects are viable. The appendix shows that if the cost of supplying gas and/or electricity to a greenhouse is less than typical end-user prices for energy, then there is potential for a coal mine operator or gas project developer and a greenhouse operator to negotiate a sales price that is beneficial to both parties. The analysis assumes that the greenhouse operator will only be interested in purchasing energy from a coal mine if the energy price is less than what the greenhouse typically would have to pay for purchasing energy from a gas company or electric utility. The analysis also assumes that the coal mine operator will only be interested in selling energy to a greenhouse if the economics of such a project are more profitable than the next best alternative for using or selling the gas.

Case Study A

The first case study involves a hypothetical mine located in southwestern Pennsylvania. The mine produces two million tons of coal per year and liberates 1.2 billion cubic feet of methane a year (600 cubic feet per ton of coal mined). The coal mine already uses a methane drainage system (vertical gob wells). The mine drills approximately ten gob wells every year and total methane recovery from all wells is approximately 300 million cubic feet of methane annually. The heating value of the gas is roughly 850 Btu/cf, as the recovered methane is mixed with mine air. Exhibit A-1 provides more information about the coal mine.

Appendix A: Case Studies

Exhibit A-1: Characteristics of Coal Mine A

Location	Southwestern Pennsylvania
Annual Coal Production	2 million tons
Specific Emissions	600 cubic feet of methane per ton of coal mined
Annual Methane Recovered	Methane Recovered from Degasification Systems: 300 million cf of methane/year (roughly 300 billion Btu/yr) (25% of total methane liberated)
Type of Degasification System	Gob Wells Only
Number of Wells Drilled Per Year	10
Gas Production Per Well	30 million cubic feet of methane
Gas Quality	On average, recovered gas is 85 percent methane, 15 percent air
Mine Lifetime	Expected Lifetime: 20 years

A greenhouse company is evaluating the possibility of constructing a new, very large greenhouse near the mine to take advantage of the CMM for heating. The company estimates that their new greenhouse would require heating seven months a year (from October through April). Since the immediate vicinity around the mine is hilly and would only be suitable for a very small greenhouse project, the greenhouse company evaluating this opportunity considers two other sites for the location of the facility.

The first site consists of flat farm land that could accommodate a greenhouse of about 0.5 million square feet. The farm land is located four miles from the coal mine. This greenhouse would have heating needs of 15 billion Btu per month (roughly 15 million cubic feet of methane) for seven months a year (105 billion Btu per year). Another, much larger piece of flat land is located eight miles from the mine. This property could accommodate a greenhouse with a size of 1.5 million square feet. The second property would have monthly heating requirements of 25 billion Btu per month for seven months a year (175 billion Btu per year). Both sites are located in close proximity to a major highway. Aside from the distance to the coal mine and the maximum potential size of the greenhouse, the two sites have similar conditions (e.g., availability and cost of labor, taxes, access to markets, weather conditions). The economic development authority in the county has offered to assist the greenhouse operator regardless of the site selected. Exhibit A-2 provides summary information regarding the two potential sites.

Exhibit A-2: Comparison of Characteristics for Two Potential Greenhouse Sites

	Location 1	Location 2
Distance from mine	4 miles	8 miles
Size (million square feet)	0.5	1.5
Monthly Fuel Use (Billion Btu)	15	25
Months of Heating Required	7	7
Annual Fuel Use (Billion Btu)	105	175

Meanwhile, the coal mine operator is working with a gas project developer to find a profitable use for the methane that is currently being emitted from gob wells at the mine. The gas project developer is evaluating two project opportunities: 1) selling methane to a greenhouse operator, and 2) selling methane to a pipeline company that owns several transport pipelines in the area. The coal mine does not have any major on-site uses for the gas and a power generation project does not appear to be economically feasible due to the low electricity prices in the area.

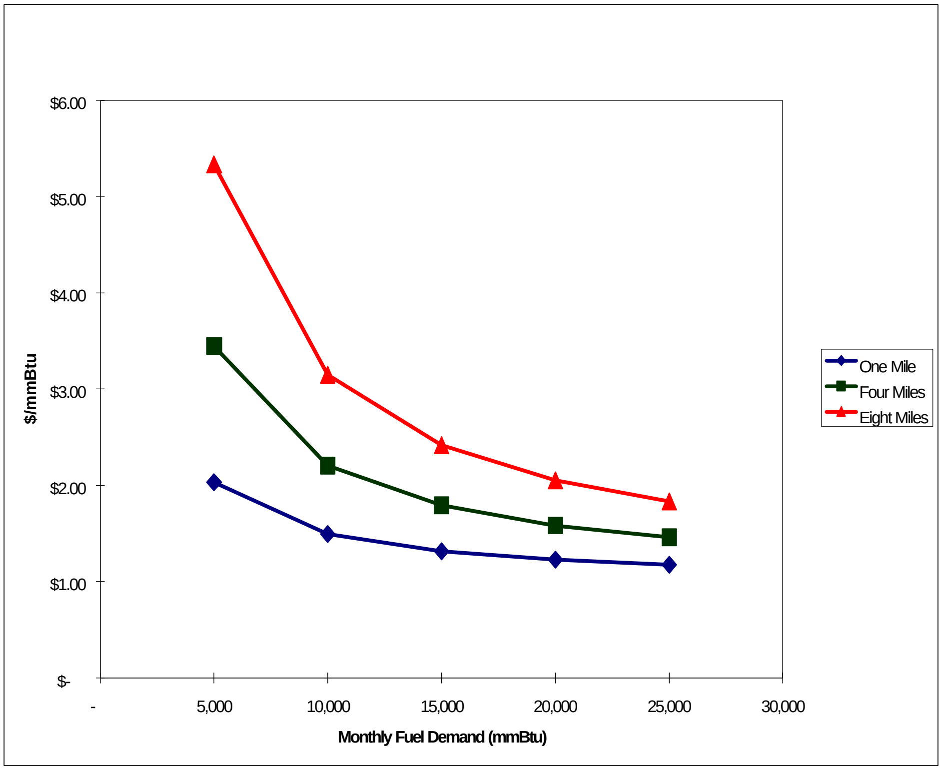
The gas project developer plans to handle all aspects of the methane use project, including purchasing and installing all the equipment and managing and maintaining the system. The project developer would pay the coal mine operator a 13 percent royalty on all proceeds from the gas sales. If the greenhouse operator purchases gas from the coal mine, he/she would not be responsible for any of the project costs or maintenance associated with the project. The greenhouse operator would only be responsible for retrofitting a standard gas-fired boiler so that the boiler would operate on coal mine methane (estimated cost of approximately $500).

The major costs to the gas project developer of selling gas to a greenhouse include the costs of compressors, of gathering and main pipelines and of a gas dehydrator. No gas enrichment (removal of air from gas to increase the quality of the gas) or blending of the coal mine methane with a higher quality gas to increase overall gas quality is necessary. Based on these supply costs and the royalty payments to the coal mine operator, the gas project developer calculates the ($/mmBtu) cost of supplying gas to a greenhouse that would purchase gas seven months per year. These costs vary substantially based on the amount of gas purchased by the greenhouse and the proximity of the facility to the coal mine. Exhibit A-3 shows the costs of supplying gas to a greenhouse facility (assuming different distances between the greenhouse and the coal mine) for this particular mine. (The costs for other mines could vary significantly.)

As shown in Exhibit A-3 the cost of supplying gas declines substantially depending on the amount of fuel that the greenhouse would purchase. The $/mmBtu cost declines because there are significant fixed costs that the gas project developer will incur regardless of the amount of gas the facility purchases. Additionally, Exhibit A-3 shows that the proximity of the facility to the coal mine also has a large impact on the cost. The cost of installing a pipeline (including materials, labor, and right of way) can be very high. For this sample hypothetical mine, estimated costs are $15 per foot.

While Exhibit A-3 shows the costs of supplying gas to a greenhouse, the gas project developer will need to sell the gas at a higher price in order to make a profit on the project. Accordingly, the supply costs shown in Exhibit A-3 do not reflect the price at which the gas project developer and/or coal mine operator would be willing to sell gas to the greenhouse. The gas sales price would need to be high enough to ensure that the gas project developer attains a certain rate of return on the project. Additionally, the project must be more profitable than other possible uses for the gas.

Exhibit A-3: Cost of Supplying Gas to Greenhouses for Coal Mine A



The gas project developer believes, however, that selling gas to a pipeline may be more profitable, because gas transport pipelines are already located on the mine property, and because the gas pipeline company would be able to purchase the maximum amount of gas available twelve months a year (as opposed to seven months a year for the greenhouse project). However, pipeline companies require that the gas content be over 97 percent methane. Because the gob gas is mixed with coal mine air, the gas project developer would either need to enrich the gob gas or blend the gas with pure methane.

To determine whether selling gas to a pipeline or selling gas to a greenhouse is the more feasible option, the gas project developer performs an analysis. Exhibit A-4 outlines the major project costs for both the greenhouse project and the pipeline project. If the pipeline project did not require gas enrichment, the break-even cost would only be $0.75/mmBtu. However, the project would require gas enrichment if the gob gas were to be injected directly into the pipeline. Gas enrichment costs would increase the cost of the project by at least $1.50/mmBtu, for a total cost of at least $2.25/mmBtu. This is significantly higher than the wellhead gas price that is offered by the pipeline company. Thus, the gas project developer determines that gas enrichment is not feasible.

Exhibit A-4: Comparison of Costs for Pipeline and Greenhouse Projects
(Comparison of Costs to Coal Mine or Gas Project Developer of Supplying Gas)

	Pipeline Sales	Greenhouse Site 1	Greenhouse Site 2	Notes
Energy Demand Per Month (Billion Btu)	25	15	25	
Months of Gas Sales Per Year	12	7	7	
Number of Wells Used to Produce Gas for Project	10	6	10	Greenhouse at Site 1 does not require full amount of gas recovered by mine.
Capital Costs				
Wellhead Compressors ($5,000 each)	$50,000	$30,000	$50,000	
Satellite Compressor	$100,000	$60,000	$100,000	Compressor costs dependent upon gas flow rate.
Sales Compressor	$100,000	NA	NA	Needed for pipeline project to boost gas to high pressure.
Main Gathering Line	$39,600	$316,800	$633,600	$15/foot; Greenhouse Site 1 is four miles. Greenhouse Site 2 is 8 miles. Pipeline is 0.5 miles.
Dehydrator	$40,000	$40,000	$40,000	Dehydration is the only processing required for greenhouse project.
Safety and Other Equipment	$60,000	$60,000	$60,000	
Contingency (at 15%)	$58,440	$76,020	$132,540	
Total Capital Costs	$448,040	$582,820	$1,016,140	
Annual Costs				
Installation & Moving of Wellhead Gathering Lines	$50,000	$30,000	$50,000	Number of Wells x 500 feet per well x $10 per foot.
Other Operations & Maintenance	$20,000	$12,000	$20,000	
Salaries	$50,000	$30,000	$50,000	
Total Annual Cost	$120,000	$72,000	$120,000	
Project Cost Not Including Enrichment ($/mmBtu)[1]	$0.75	$1.79	$1.84	
Project Cost Including Gas Enrichment ($/mmBtu)	>$2.25	$1.79	$1.84	Estimated minimum gas enrichment costs are $1.50/mmBtu. Enrichment not required for greenhouse projects.

[1]Project costs assume 40% tax rate, 15% nominal discount rate.

Case Study B

The next case study involves a hypothetical coal mine located in West Virginia. The coal mine produces one million tons of coal per year and liberates a total of 1.2 billion cubic feet of methane per year (1,200 cubic feet per ton of coal mined). Of the total amount liberated, gob wells account for 300 million cubic feet (or 25%). Accordingly, Coal Mine B recovers the same amount of methane from its gob wells as does Coal Mine A (described in Case Study A). However, as described in further detail later in this section, Coal Mine B has significantly lower project costs than does Coal Mine A. Because of gassier seams and different mining conditions, Coal Mine B is able to use fewer wells to recover the same amount of methane (Coal Mine B drills five wells per year, compared to Coal Mine A, which drills ten wells per year). Exhibit A-5 provides details about Coal Mine B.

Exhibit A-5: Characteristics of Coal Mine B

Location	West Virginia
Annual Coal Production	1 million tons
Specific Emissions	1200 cubic feet of methane per ton of coal mined
Annual Methane Recovered	Methane Recovered from Degasification Systems: 300 million cf of methane/year (roughly 300 billion Btu/year)
Type of Degasification System	Gob Wells Only
Number of Wells Drilled Per Year	5
Gas Production Per Gob Well	60 million cubic feet of methane
Gas Quality	On average, recovered gas is 80 percent methane, 20 percent air
Mine Lifetime	Expected Lifetime: 20 years

The operator of Coal Mine B has contracted with a gas project developer who is trying to identify the most profitable way in which to use the gas liberated from gob wells. The gas project developer is especially interested in selling the gas to a large industrial or commercial facility with high demand for natural gas. The average energy value of the gas liberated from the gob wells is about 800 Btu per standard cubic foot (because the gas contains some mine air). Due to the lower energy value of the gas, the gas project developer does not believe that selling methane to a pipeline would be a feasible option (because the gas would either need to be enriched, spiked, or blended). Furthermore, the gas project developer is not interested in developing a power generation project, due to the low electricity prices in the area.

The gas project developer has been working with the local economic development council. The economic development council also wants to encourage a new industrial or commercial facility to locate in the area, and has identified some available land. Located four miles from the coal mine, the land could accommodate a large facility. The economic development council has put together a brochure describing the favorable tax rates, available labor, and good access to northeastern markets that the area offers.

The economic development council has asked the gas project developer to put together some estimates on gas supply and prices that could be used to attract a large facility.

The gas project developer realizes that some types of facilities would need gas on a year-round basis, while other facilities might only need gas for heating during the late fall, winter, and early spring. Due to the substantial fixed costs associated with supplying gas to the site, the cost of supplying gas is significantly lower on a $/mmBtu basis for facilities that would purchase larger volumes of gas. Supply costs are also lower for a facility that would purchase gas on a year-round basis. Projects that purchase gas only part of the year result in capacity that is not used for the remaining months of the year. For example, Exhibit A-6 compares the costs of supplying gas to two large industrial or commercial facilities that have the same annual energy needs. One facility requires energy for only seven months a year; the other facility requires less gas each month than does the first facility, but uses gas on a year-round basis. The second facility has lower gas supply costs. This is because there are higher capital and operating costs associated with setting up the gas gathering system for the first project (more wellhead compressors, larger satellite compressors). In conjunction with the higher costs, the system is not used for five months a year (and, thus, no revenues are gained from sale of the gas).   However, even for facilities that would purchase gas for only seven months per year, the supply cost is significantly lower than the typical industrial or commercial end-user price of purchasing gas (see Exhibit A-7).

Exhibit A-6: Cost of Supplying Gas for Mine B

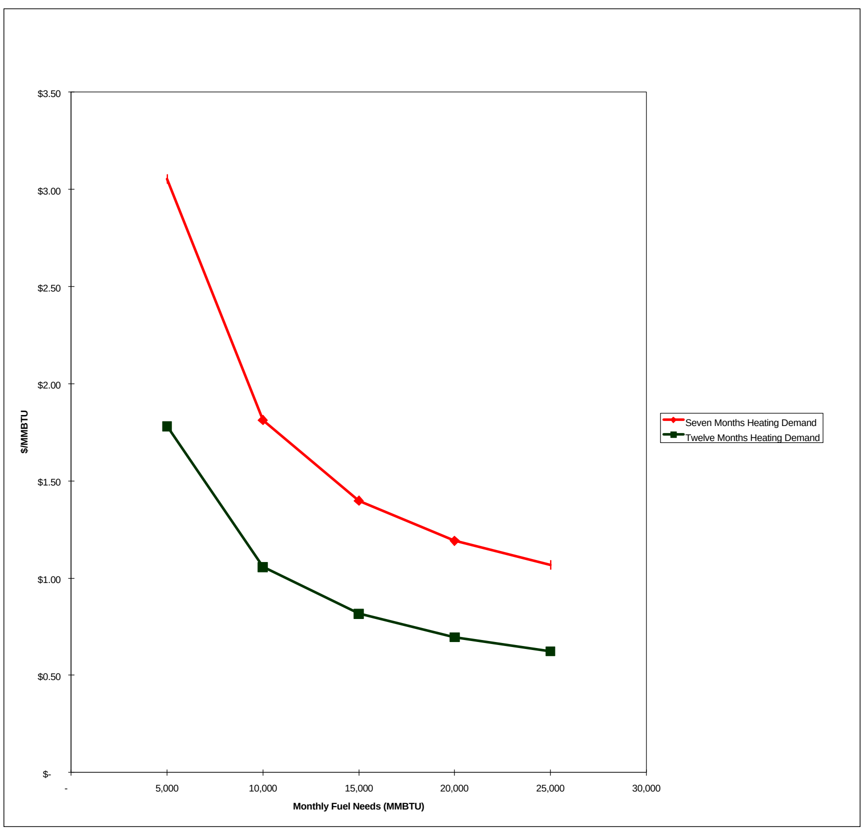


Exhibit A-7: Comparison of Project Costs for Facilities with Different Seasonal Fuel Needs

	Facility 1	Facility 2
Monthly Fuel Purchases	12 Billion Btu	7 Billion Btu
Number of Months Per Year Fuel is Purchased	7 months	12 months
Annual Fuel Purchases	84 Billion Btu	84 Billion Btu
Cost of Supplying Gas	\$1.61/mmBtu	\$1.37/mmBtu

The gas project developer and economic development authority identify a greenhouse operator that is planning on constructing a new, large greenhouse. The greenhouse would be approximately 0.3 million square feet and would have monthly heating requirements of approximately 10 billion Btu. The greenhouse would require heating seven months per year. For Coal Mine B, the cost of supplying gas to this greenhouse would be \$1.80/mmBtu. However, the gas project developer would need to charge a higher price in order to make a profit on the project and to achieve a target rate of return.

The gas project developer and greenhouse operator agree upon a gas sales price of \$3.00/mmBtu, which is \$1.00 less than the typical commercial and industrial end-user gas prices in the area. At this price, the greenhouse will achieve annual savings of \$70,000. The net present value of these savings over a twenty-year time period is \$586,000. At this price, the estimated net present value of the project to the gas project developer is \$0.4 million (with an internal rate of return of 25 percent and a payback period of 5 years). Finally, the coal mine operator receives royalty payments from the gas sales equaling \$26,250 per year. The net present value of these proceeds is \$306,000.

Coal Mine B can supply gas to a greenhouse with monthly heating needs of 10 billion Btu located four miles away at a cost of \$1.81/mmBtu. In comparison, Coal Mine A's cost of supplying gas to a greenhouse with the same heating requirements, located the same distance from the coal mine is \$2.20/mmBtu. As mentioned previously, Coal Mine B is able to produce larger volumes of gas from individual wells than Coal Mine A. Accordingly, Coal Mine B has lower per well costs (examples of per well costs include costs of wellhead compressors and cost of gathering lines from individual wells). Exhibit A-8 compares the costs of supplying gas to greenhouses for the two different mines.

Exhibit A-8: Comparison of Cost of Supplying Gas to Greenhouses

Greenhouse Energy Needs (million Btu/month)	Coal Mine A	Coal Mine B
25,000	$ 1.46	$1.07
20,000	$1.58	$1.19
15,000	$1.79	$1.40
10,000	$2.20	$1.81
5,000	$3.45	$3.05

Notes: Assumes greenhouse requires heating seven months per year. For both mines, greenhouses are located four miles from the mine site.

Case Study C

Case Study C involves a hypothetical coal mine located in Alabama. The coal mine produces one million tons of coal every year and liberates 2,000 cubic feet of methane for each ton of coal mined (or 2 billion cubic feet of methane per year). The coal mine is already selling all of the methane recovered from vertical wells and horizontal boreholes to a nearby pipeline company. Additionally, the mine is selling a very small amount of gob gas to a pipeline company (the mine blends some of the higher quality gob gas with the high heating value gas recovered from the vertical and horizontal wells). However, the mine has not been able to find economic uses for the remaining large volumes of methane liberated from the gob wells. Exhibit A-9 describes the characteristics of Coal Mine C.

Exhibit A-9: Characteristics of Coal Mine C

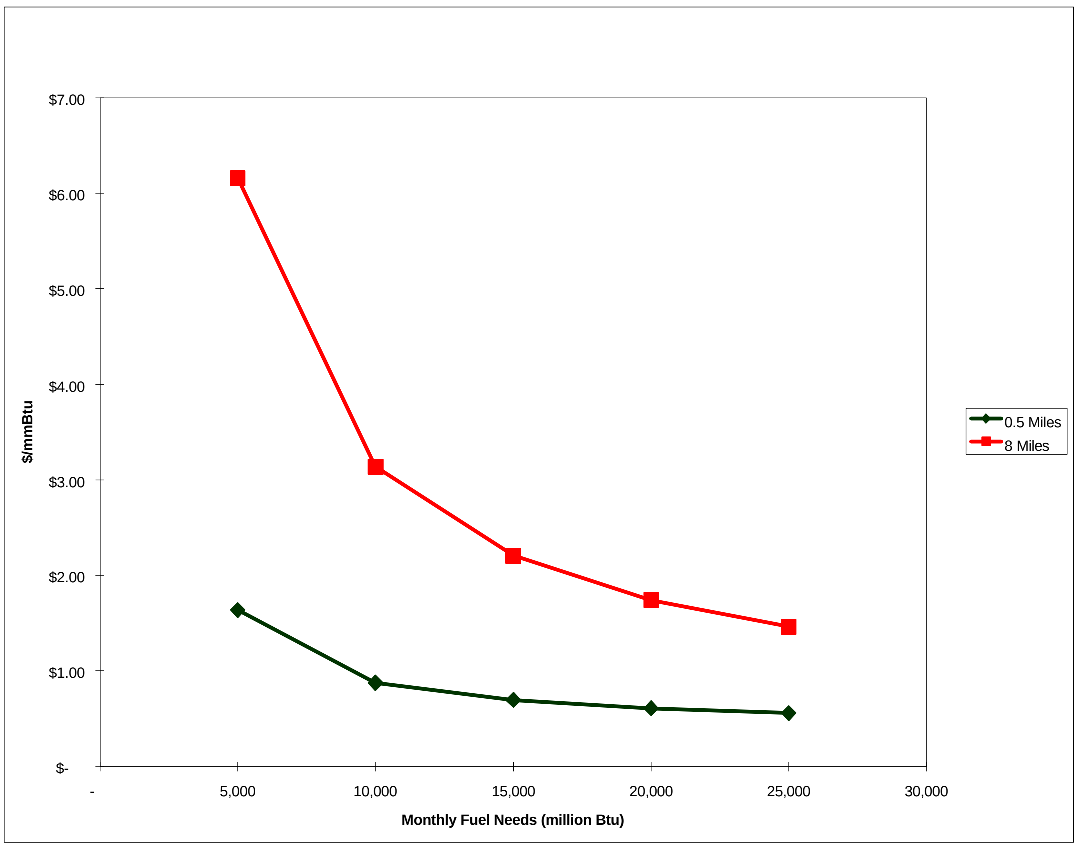
Location	Alabama
Annual Coal Production	2 million tons
Specific Emissions	2,000 cubic feet of methane per ton of coal mined
Type of Degasification System	Vertical pre-mine, horizontal borehole, vertical gob
Annual Methane Recovered	Mine sells methane recovered in advance of mining from vertical wells and horizontal boreholes to a pipeline company
Gas production per gob well	83 million cubic feet per year
Mine Lifetime	Expected Lifetime: 20 years

A greenhouse company has expressed interest in locating a new facility near the mine in order to purchase gob gas for heating. The greenhouse company is planning on constructing a moderate-sized greenhouse and is eager to find out whether such a project would be economic. The size of the planned facility is 0.1 million square feet. The greenhouse would have monthly heating requirements of 5 billion Btu per month and would require heating only five months a year. The coal mine operator is willing to lease land to the greenhouse. The land is located less than one mile from several of the mine's current active gob wells.

The gas project developer who handles the sale of the gas to the pipeline is interested in the greenhouse project. The greenhouse project would involve setting up a separate set of gathering lines to handle the lower Btu gob gas. However, the project developer could use the existing wellhead compressors located at the gob wells for the greenhouse project, which would help to lower project costs. Additionally, the gas project developer does not believe that they will need to hire additional staff to handle the greenhouse project. Finally, because of extensive experience at this site, the gas project developer believes that planning costs for the greenhouse supply project should be minimal.

The gas project developer estimates the cost of supplying gas to greenhouses. In estimating the $/mmBtu cost, the project developer takes into account the capital and operating costs, and the royalty payment of 13 percent owed to the coal mine operator. Exhibit A-10 shows the cost of supplying gas to greenhouses with varying energy needs and locations. As shown in Exhibit A-10, the project developer's cost of supplying gas to a greenhouse that has energy needs of 5 billion Btu per month, located half a mile from the coal mine, is $1.64/mmBtu. The gas project developer will need to charge a higher rate, however, in order to make a profit on the project.

Exhibit A-10: Cost of Supplying Gas to a Greenhouse for Mine C



The gas project developer and greenhouse operator agree on a price of $2.75/mmBtu. This price is about $1 less than the typical end-user rates for a large commercial facility in the area. By participating in this project, the greenhouse operator will realize annual savings of $25,000. The net present value of these savings is $200,000 for a 20-year project. For the gas project developer, the project has a net present value of $141,000 and an internal rate of return of 27%. Finally, for the coal mine operator, the annual royalty payments are $8,600 and the net present value of the payments is $100,000.

Exhibit A-10 shows that even though the greenhouse is significantly smaller than the greenhouses discussed in Case Study A and Case Study B, the gas project developer would still be able to supply gas at a price that is lower than typical end-user gas prices. Coal Mine C has lower project costs compared to Coal Mine A and Coal Mine B. At Coal Mine C, the greenhouse could be located very close to the mine and some of the labor and equipment costs would already be covered as part of the existing pipeline sales project.

Case Study D (Electricity and Heating)

Case Study D involves a hypothetical coal mine in Colorado that already is using methane recovered from gob wells to generate electricity to meet the power needs of the mine. The total level of electric capacity that could be generated from methane recovered from gob wells is 8 MW. However, the mine currently is only using enough gob gas to generate 6 MW, which is approximately 1 MW higher than the coal mine's baseload capacity. When the mine is in full operation, the electric capacity demands can reach up to 14 MW. For its remaining electricity needs, the coal mine purchases electricity from the local electric utility. Exhibit A-11 summarizes the MW capacity demands of the mine.

Exhibit A-11: Electric Capacity Demands at Coal Mine D

Level of Electric Capacity	Percentage of Time During Year That Coal Mine Capacity Needs Equal MW Level Shown at Left
At least 5 MW (Baseload)	100%
Between 5 and 6 MW	80%
Between 6 and 7 MW	50%
Between 7 and 8 MW	35%
Between 8 and 10 MW	25%
Between 10 and 12 MW	15%
Between 12 and 14 MW	5%
Greater than 14 MW	0%

Coal Mine D is considering possible uses for the remaining amounts of gob gas not used in the current power generation project. One possibility would be to use the gob gas to generate additional electricity to meet the additional operating needs of the mine (above baseload needs). Coal Mine D currently uses several 1 MW internal combustion engine units to generate the 6 MW of power used to meet the baseload and a portion of the additional operating capacity of the mine. Coal Mine D is considering purchasing another 1 MW unit to increase the level of electric capacity generated.

Currently, the local electric utility charges five cents per kWh for very large industrial facilities, such as the coal mine. Thus, the coal mine operator is avoiding paying five cents per kWh to the utility for its baseload project. The mine has estimated that its cost of generating electricity for the existing power project is less than 3 cents per kWh. However, the coal mine operator realizes that the marginal cost of generating electricity to meet the electric requirements of the coal mine will be more than 3 cents per kWh. The capacity factor of the existing project is very high (nearly 100% for the baseload portion, except for repair and maintenance, plus 80% for the next one MW of capacity yields an overall capacity factor of nearly 90 percent). However, if the coal mine installed an additional 1 MW of capacity to meet a portion of the incremental operating needs of the mine, the capacity would not be fully utilized. In fact, the mine operator estimates that the capacity factor (percentage of capacity used during the year) of another 1 MW generator would only be 50% (see Exhibit A-11). The incremental capital cost of adding another 1 MW unit is high -- $800 per kW installed capacity. Accordingly, the lower the capacity factor, the more difficult it is to be able to cover the initial capital cost of the generator. Based on preliminary calculations, the mine operator has concluded that it would not be economic to install another MW of capacity.

A greenhouse operator has approached the manager of Coal Mine D regarding purchasing some of the electricity generated at the mine. The greenhouse operator is trying to decide upon the best location for constructing a new large greenhouse. The state-of-the art greenhouse will have numerous automated features, many of which require electricity to operate. Accordingly, the greenhouse operator is interested in finding a location where they can purchase electricity at low rates. The greenhouse will have estimated baseload energy needs of 375 kW and total annual electricity needs of 3.3 million kWh per year. The local electric utility charges six cents per kWh for large commercial facilities (such as the greenhouse).

The coal mine operator is interested in supplying electricity to meet the greenhouse's electricity needs. Supplying power to meet the greenhouse's baseload and additional electricity needs will greatly improve the mine's ability to use more of the installed capacity if they add another 1 MW unit. The addition of the greenhouse project should increase the capacity factor to 87% for the incremental 1 MW. Furthermore, the greenhouse operator is willing to pay five cents per kWh for electricity purchased from the coal mine (a savings of one cent per kWh over the price offered by the local utility). Exhibit A-12 presents a comparison of the costs and benefits of selling electricity to the greenhouse compared to using the additional capacity only for on-site electric needs at the mine.

Exhibit A-12: Comparison of Electricity Projects
(from Coal Mine Operator's Perspective)
Incremental Costs and Benefits of Adding a 1 MW Unit

	Coal Mine Only	Coal Mine and Greenhouse Combined Project
Incremental Electricity Used at Mine and Greenhouse (kWh/year)	4.4 million	7.7 million
Electricity Used at Greenhouse (kWh/year)	NA	3.3 million
Value of Electricity Savings at Mine ($/kWh)	5 cents	5 cents
Value of Electricity Sold to Greenhouse ($/kWh)	NA	5 cents
Annual Value of Electricity Savings at Mine	$220,000	$220,000
Annual Value of Electricity Sold to Greenhouse	NA	$165,000
Total Annual Value of Electricity	$220,000	$385,000
Incremental Capital Cost for Additional 1 MW Unit ($800 per kW installed capacity)	$800,000	$800,000
Incremental Annual Operating Cost	$22,000	$25,000
NPV of Project to Coal Mine Operator	$-386,670	$37,524
IRR of Project to Coal Mine Operator	-2%	16%

The NPV of the project that includes selling electricity to a greenhouse is significantly higher than using the electricity only for on-site needs ($37,524 compared to $-386,670). The greenhouse operator will realize annual electricity savings of $165,000. The net present value of these savings over a ten-year time period is greater than $0.8 million. Accordingly, the mine and greenhouse decide to proceed with the project.

In addition to purchasing electricity from the mine, the greenhouse is also interested in purchasing gas for heating during the winter months. Even though the coal mine already uses gob gas for the power project, the coal mine still has additional gob gas available. Furthermore, because the coal mine has already invested in a gas gathering system, the incremental costs of establishing a separate line to transport gas to the greenhouse are relatively low. The gas heating project will yield additional financial benefits for both parties.

Summary of Case Studies

The four case studies above show that CMM/greenhouse projects can be beneficial for greenhouse operators, coal mine operators, and gas project developers. In all four case studies, the parties were able to establish a gas and/or electricity sales price that led to economic benefits for all involved.

The case studies show that the energy needs of the greenhouse and distance from the greenhouse to the coal mine have a large impact on the cost. The case studies show that the ($/mmBtu) costs of supplying gas to very large greenhouses with high energy needs will be significantly lower than the cost of supplying gas to smaller greenhouses. Nevertheless, small greenhouse projects may still be economic. Additionally, the case studies show that the distance between the coal mine and the greenhouse is also a significant factor impacting the gas supply cost. Small greenhouses will need to be located very close to the mine site. For larger greenhouses, the project may still be economic even if the greenhouse is located several miles from the coal mine. However, the supply cost (and, thus, the gas sales price) will increase with distance. The number of months a year that the greenhouse will purchase energy also impacts price (as explained in Case Study 2). Even greenhouse projects that would entail gas sales purchases only five months a year, however, can still be profitable for all parties involved.

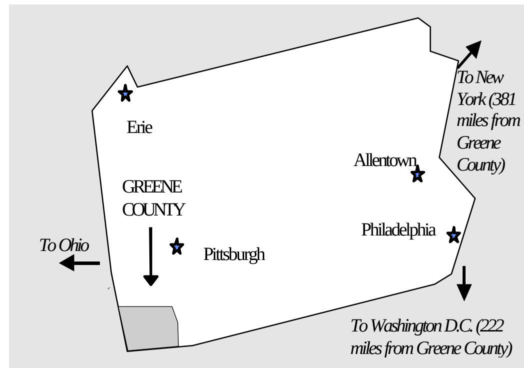
The case studies also show that the cost of supplying gas to a greenhouse will vary significantly from one coal mine to the next. For example, the cost of supplying gas to a greenhouse was very different for Coal Mine A compared with Coal Mine B, even though the distance to a greenhouse was the same for both mines. Examples of factors that impact the cost of supplying gas include the number of wells needed to meet the gas supply, needs of the greenhouse, the terrain surrounding the mine (impacts cost of laying gathering lines), and whether the coal mine already has a gas gathering system in place.

In conclusion, though the cost of supplying gas to a greenhouse will vary significantly depending on the characteristics of both the coal mine and the greenhouse, CMM/greenhouse projects are likely to be profitable ventures under a wide range of conditions.

Appendix B: County Profile

The following profile of Greene County, PA illustrates the various issues that determine the feasibility of locating a greenhouse near a coal mine from the perspective of the greenhouse operator.

Local Project Data



Candidate coal mines. Coal mines situated in the county include Cumberland and Emerald (owned by Cyprus/AMAX), and Dilworth, Bailey and Enlow Fork (owned by CONSOL). Estimated methane emissions from degasification systems in 1996 were as follows (in million cubic feet per day): Cumberland, 1.6; Emerald, 3.9; Dilworth, 1.7; Bailey, 3.3; and Enlow Fork, 5.7. As of 1996, none of these mines were using the drained methane, so greenhouse operators may want to situate near these mines so that they can take advantage of the coal mine resources.

Fuel Cost and Availability. In 1997, Allegheny Power, the local electricity supplier, charged industrial customers from 3.73 to 4.16 cents per kWh, and commercial customers from 4.75 to 11.13 cents per kWh. These rates do not include peak demand charges. Natural gas costs about $6 per thousand cubic feet (mcf) for commercial use and $4 per mcf for industrial use.

Water Cost and Availability. Greene County has an adequate water supply. Southwestern Water Authority is the major water supplier for the area. Local water prices quoted by the water authority in 1997 are $4.11 per thousand gallons and $3.99 per thousand gallons above 5,000 gallons in any given month. In addition, a local company, Higgins Hauling, can haul water within a ten-mile radius of Waynesburg, PA at a cost of $50 per 2,000 gallons (Higgins 1995). Another possible source of water may be the water produced by coal mines.

Land Ownership. The candidate coal mines above are all situated in the Waynesburg, PA area. The land availability and property costs in the Waynesburg area differ widely. Land prices close to the interstate highway can be as high as $175,000 per acre. Moving away from the interstate, prices are much lower and generally range from $700 to $2,500 per acre. (Heritage 1995). Land that is not owned by the coal company is mostly owned by businesses and industries. Depending on the agreement reached, it may be possible to lease land from the coal mine.

Climate. The area has a reasonable climate for operating a greenhouse (Brown 1995). The snow load in the area is between 5.4 and 10.8 pounds/square foot. The maximum expected wind would not be above 80 mph, and, if situated in a valley, the greenhouse would be protected from strong winds. There are about 6,000 heating degree days for the area (Walker 1973A).

Access to Markets. The Emerald Mine is located near the main artery road in Waynesburg and is within a few miles of Interstate 79. Cumberland is slightly farther from the Interstate highway and the roads leading to the coal mine are narrow and winding. Bailey and Enlow Fork are located about 10 miles from the Interstate. Pittsburgh is 40 miles from the county, New York City is approximately 380 miles away, Philadelphia 325 miles away, and Washington, D.C 222 miles away. These cities are readily accessible via inter-state highways.

Tax Structure and Zoning Laws. Glass greenhouses are taxed as permanent structures. Tax is based on greenhouse square footage, the age of the house, and the type of construction. The tax structure considers plastic greenhouses to be temporary structures and they are therefore not subject to property taxes.

Other Greenhouses in Greene County, PA. Most produce grown in Pennsylvania greenhouses is sold in-state, since there are ample markets in Pittsburgh, Philadelphia, and other large cities. If the greenhouse is close to the state border, products may also be sold in neighboring states (e.g., Maryland, West Virginia). In the end, though, the determination of whether produce is sold in-state or out-of-state is market-based. Usually, out-of-state sales are restricted to the DC and NY corridor because a large and relatively affluent population is in close proximity. Rarely are commodities shipped to mid-western markets because many greenhouses are already thriving in those areas (Dunn 1995).

Existing Greenhouse Industry Profile

Currently, there are at least seven greenhouses in Greene County. As in most of western Pennsylvania, these are mostly small, family-owned greenhouses. They usually are part of an operation that includes small outdoor growing facilities and a retail stand or store in which to sell the produce or plants. In other parts of western Pennsylvania, there are several larger greenhouses. However, the number of large greenhouses in Pennsylvania is decreasing as buyers purchase many wholesale greenhouse products from larger, automated greenhouses in Ohio.

The following points summarize data on the local greenhouse industry:

- **Size.** Sizes of greenhouses in western Pennsylvania range from one-tenth of an acre, for a single house, to six acres, which usually includes several houses attached together with gutters. In Greene County, most greenhouses are small (Walker 1995).

- **Materials.** Most greenhouses in the area are covered with two layers of plastic. Construction and heating costs are both lower for plastic.

- **Heating Systems.** These smaller greenhouses most commonly use unit heaters fueled by natural gas. Boilers are used less frequently (Survey 1993).

- **Cooling Systems.** Greenhouses in the area do not use refrigeration for cooling purposes because costs are high. Usually, the climate conditions do not require this type of cooling since most greenhouse growing occurs in the non-summer months (Brown 1995).

- **Business Structure.** Most small greenhouses in Greene County are family-owned and operated. They grow mostly bedding and potted plants, flower crops, vegetables, and seedlings for transplanting in fields, and sell their products at local retail markets (Willmott 1995). None are currently using coal mine methane as a fuel source.

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